VAN NOSTRAND'S

ENGINEERING MAGAZINE.

NO. CLXXVII.—SEPTEMBER, 1883.—VOL. XXIX.

THE PROGRESS OF TELEGRAPHY.

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From Proceedings of the Institution of Civil Engineers.

It is my misfortune, and not my fault, that I have to lead off this course of lectures on the Practical Applications of Electricity. It is my misfortune because it happens that Telegraphy is the oldest and the first of these practical applications, and though it is the oldest and the first, nevertheless it is very young, for it dates its birth only from the year 1837. The great shining lights of this Institution were present at its birth, and Robert Stephenson, Isambard Kingdom Brunel, Joseph Locke, and George Parker Bidder, were its godfathers. There are many (and doubtless there are some present to-night) living members of this Institution who assisted materially in its delivery. It grew around our railway system, and our railway managers were not slow in detecting the power that telegraphy gave them to marshal their trains, to adjust their traffic, and to protect life. In 1851 this art, if I may so call it, had scarcely commenced to take a commercial existence, but now it is only necessary to refer to the map to see to what an enormous extent telegraphy has grown.

A civil engineer would feel himself disgraced if he knew nothing of the strength of materials, of the pressure of liquids, of stresses and strains; but how many amongst my hearers are there who know much of electromotive force, of resistance, of currents, of volts, of induction, *et hoc genus omne*. An American author has told us that it is very dangerous to prophesy unless you know; but I think I am justified in prophesying this, that it will not be very long before these terms become household words, for they have already been admitted into commercial, legal, and parliamentary lore.

Now, gentlemen, what is electricity? Electricity, as we know it and use it, is a mere form of energy; it is brought into existence when it is wanted, and it disappears when it has done its duty. "Like the snowfall on the river—a moment white, then melts for ever." Like sound and light and heat, electricity is a mere abstract idea; it has neither substance nor shadow. Supposing I take a matchbox, and out of that box I take a match, is there any man in this room who would say that in the head of that inert match we have light and heat? And yet when I strike that match we excite both heat and light. Would anybody say that in this bell I have sound? And yet when I strike that bell I produce sound. So, when I take a piece of zinc, will anybody tell me that in that zinc there is electricity? There is something, for the mo-

ment when I put this zinc into that battery, I have started something going, the bell rings violently; and the moment I take that zinc out, that something has ceased, for the bell becomes silent again. This zinc contains what the match contains, what my blow produced—energy; and it has simply been the conversion of this energy, first into one form producing chemical action, then into another form producing electric currents, then into a third form producing magnetic power, which produced that other form—sound, which made that bell audible to you all. Now, much brain-wasting power has been devoted in trying to picture some conception of this thing called electricity, but we cannot conceive the existence of that which does not exist. That which exists is energy, indestructible, convertible, and we in our practical applications merely utilize it in its electrical form. My duty to-night is to show you how we employ this particular form of energy and transmit it to the uttermost parts of the earth, there to do work, to express our wishes and our wants.

Now, this electrical form of energy possesses certain properties. It is found in a *potential* or passive state, and in a *kinetic* or active state. We have *electromotive force*, a term that is simply analogous to "head," when we speak of water, "pressure," when we speak of gases, "temperature," when we speak of heat; electromotive force in fact is simply a term analogous to difference of level, to the difference of potential energy that determines the flow of liquids. When we possess this difference of potential or electromotive force, we can produce a *current*, or the kinetic form of electrical energy, provided we supply a path for this flow of energy. It is impossible, with the materials at our command, to find anything that does not more or less oppose or resist the flow of electricity. Hence, materials possess what is called *resistance*, and electromotive force and resistance are expressed in definite magnitudes; they can be measured with greater exactitude than any other system of magnitude at the command of the engineer. The engineer can measure feet and inches and the thousandth part of an inch, but the electrician can measure the millionth part of an inch; in fact there is no magnitude or force in Nature that can be practically measured with greater exactitude and in more minute dimensions. The unit to which electromotive force is referred is called the *volt*, and that to which resistance is referred the *ohm*, while the unit current is called the *ampere*.

The great progress that has been made in telegraphy, and the great advances that have been made in the science of electricity, are due to the power that this system of exact measurement has given the engineer. Now, having at our command this form of energy, and being able to overcome resistance by its means and transmit it to a distance, the question arises, How is it produced? It is produced in nearly every form of telegraph by the simple combustion of zinc, in either sulphuric acid or some solution in which sulphuric acid bears an intimate part. There are exceptions. We have sodium chloride, and there are other liquids, but practically and generally the form of chemical action which takes place is the conversion of zinc into zinc sulphate. Now, without running you through the elementary details of the voltaic cell—a matter absolutely impossible within the hour and a half devoted to the subject—I may simply briefly point out to you the forms which these different batteries take. We have first Daniell's. In Daniell's zinc is consumed, copper is deposited, and we have a normal electromotive force that is very closely allied to our unit, the volt. But the Daniell battery has one serious defect, and that is, it works out quicker when it is idle than when it is at work—there is a considerable local action that very speedily destroys its efficiency. But Leclanche, in Paris, introduced a battery utilizing zinc acted upon by chloride of ammonium, and peroxide of manganese, in contact with coke, by which he succeeded in stopping, not only the local action, but he gave us an electromotive force 50 per cent. greater, so that ten of these Leclanché cells are equal to fifteen Daniell's. But we have gone a step further than this, by utilizing Poggendorff's discovery of the power of bichromate of potash. The result is we get a battery whose electromotive force is more than 50 per cent. that of Leclanché, twice that of Daniell's, and one that gives us an efficiency that is

simply marvelous for telegraphic work. Now, of these cells in our Post Office Department, we have 87,221 Daniell's, 56,420 Leclanché's, 22,000 bichromates; altogether we have about 165,000 cells; and by a rough calculation of the number of batteries in use throughout Europe, at the present moment, they exceed 1,200,000. There are other forms of apparatus by which we produce these currents. The mere movement of a coil of wire in front of a magnet causes those currents that are so powerful in producing the electric light, and by simply turning a handle in this way I am able, by rotating a coil of wire in front of the magnet, to create currents powerful enough to ring that bell.

Great improvements have been made in the form and efficiency of these batteries, by the application of scientific laws to the investigation of their performances; and, owing to the progress that science has made, it is quite possible to maintain batteries in a state of constant efficiency that ten years ago was absolutely impossible. By the aid of rigid tests, and by the aid of accurate instruments, we are able to maintain them, in their full state of perfection without ever deteriorating more than 25 per cent. below their normal value. The only defect that the bichromate battery has developed is a deteriorating influence on the health of the men attending to them, due to the action of mercury. Very promising experiments are being made with secondary batteries which will probably diminish this evil in all large centers.

The production of these currents of electricity being so simple and easy, the next question that arises is, How are they conveyed from place to place? We find materials divided into two classes—*conductors* and *insulators*. The conductors are materials which are transparent, as it were, to this flow of energy, and insulators are materials which are opaque; conductors offer comparatively small resistance, insulators offer great resistance. Copper is one of the best conductors; glass, porcelain, gutta-percha, are some of the worst, and therefore they are very good insulators. The first telegraphs were laid under ground. Here is a piece of a telegraph of five wires, erected between Euston and Camden, and buried underground—creosote timber, or prepared timber, with copper wire let into grooves and covered with a tongue. We call it the "fossil" telegraph. But it was speedily found that copper buried in that way could not be maintained in a condition of insulation, and therefore wires were put overground, attached to poles and insulators. In England, hitherto, we have invariably used wood creosoted, to check decay. Abroad, and in the colonies, iron is used to a very great extent, and to my left here I have one of the best—perhaps the best—iron pole that has been produced, that of the Messrs. Siemens, fitted up with insulators complete, so that you may see the form that experience has now taught us that iron should take to secure the greatest efficiency. Insulators are of all shapes and forms and sizes. Every man who has had anything to do with the advance of electricity has had a shot at a new insulator, and the result is that they are as numerous as the men who have been in power. But by dint of careful examination of all those in use throughout the world, and with the knowledge that it is essential to produce an insulator that shall be readily cleansed, this that I hold in my hand is now the form that is most generally adopted in England and India, and throughout our colonies. There is a very curious meteorological effect that we have to protect ourselves against in England, and I think England is peculiar in this respect, and for that reason the problem of insulation in England is more difficult than in any other country. The reason is this, that in England the prevailing winds blow from a warm climate to a cold one, while on the coast of America they blow from a cold climate to a warm one. Now, coming from a warm climate to a cold one, the result is that aqueous clouds speedily deposit their moisture upon anything in their progress colder than themselves, and the result is that the insulators become coated with a film of moisture—a film that is so dangerous in its consequences that sometimes the whole telegraph system of England has very nearly broken down.

The conductors are almost invariably iron, and within the last few years very great improvements have been made in the manufacture of iron wire. The im-

provements are so great that in the present day wire is exactly 50 per cent. better than it was seven or eight years ago. The No. 8 wire of the present day is as good as the No. 4 used to be. Again, wire is manufactured in long lengths; there are no welds, no joints—sources of enormous trouble in the early days of telegraphy. It has great ductility, it has considerable durability, but in the neighborhood of smoky towns, such as London, Manchester, and some of the places in the north, the decay of iron wire is very rapid. We have coated it with certain materials to try and check this decay. Those who are in the habit of travelling on the London and South-Western Railway may notice between Waterloo and Nine Elms that the material we use to preserve the iron has itself gone. It hangs in unpleasant festoons on the wire, and it was only a few weeks ago that I was asked what was that fungus that grew on the South-Western wires. The improvement in iron is so great that wire which had a breaking strain of some 25 to 30 tons now has a breaking strain of 40 to 50 tons; and wire is absolutely made for submarine cable purposes, and for long spans, with a breaking strain of 90 tons to the square inch. Copper, which is much used in districts where iron rapidly decays, has also followed in this train of improvement, and it is remarkable what variation has been found in the quality of copper. Five specimens of copper,

Samples of copper.	Conductivity.		
	1st test.	2d test.	3d test.
A	101.4	101.1	101.02
B	44.7	44.87	44.51
C	98.7	99.63	98 64
D	101.3	100.2	101.14
E	18.7	18.63	..

taken at random, were submitted to three individuals to test, and you will see that while the three individuals agreed almost exactly in their measurements, the copper varied, 100 being the standard of purity, from 18 per cent. to 101.4, or more than purity. The specific conductivity of the copper of commerce, unless checked and controlled by electrical tests, is liable to give those extremes of 44 and 101. Fortunately in telegraphy our tests are so simple that we can tell with absolute certainty the quality of the material we have; and now it is excessively rare to obtain copper for telegraphic purposes that gives less than 96 per cent. of pure copper. Compound wire, that is a small steel wire surrounded either mechanically or electrolytically by copper, has been experimentally used, but not with much success. Wire made from phosphor and silicious bronze is coming much into use, and it is a very promising material. The latter has the strength of iron, and the conductivity of copper, and if it only stands the test of time it will serve to supply a very serious want. We find now, owing to the multiplicity of wires, that our poles will not carry any more; and if any material with lightness and strength can be produced which will enable our poles to carry twice as many wires, it will be a valuable adjunct to telegraphy.

Wires are carried underground by means of gutta-percha, and the same improvements exactly that have been made within the past few years in iron have also been made in gutta-percha. The insulating qualities, the inductive capacity, the durability, and all other points, are gradually improving. We find that gutta-percha meets with enemies underground—wretched, horrible little insects that you cannot see with the eye, and can only detect with the microscope, make fine meals out of this coating of our wires, and produce considerable mischief. Vermin, mice, rats, seem to have a *penchant* for gutta-percha, so that the troubles we have are very great; but, nevertheless, gutta-percha as an insulator for telegraph purposes remains the very best material at our command. We have in England no less than 12,000 miles of underground wire, and the cry is very often raised that we ought to put all our wires in England underground. Those who make that cry do not know the difficulties that deter us from carrying that out. In the first place, the cost of putting wires underground is four times the cost of putting them overground. Next, the capacity of wires underground is only one-fourth that of wires overground, in consequence of a curious retarding influence upon the currents that slows the operations of teleg-

raphy. The result is that whenever we take into consideration any long length of underground wire, as, for instance, between London and Leeds, or London and Manchester, underground wires are commercially sixteen times worse than overground wires. You can readily therefore imagine that the authorities of the Post Office are not particularly anxious to put wires underground. We shall be very glad to do so if the Legislature will find the capital for the purpose, and the amount required to replace our system underground is only £20,000,000! Now this cry for underground work has arisen from certain snowstorms that have occurred recently. Snowstorms and their effects, like a great many other things, are very much exaggerated by the press. The press naturally makes a fuss at any rupture of communication, for it checks the news transmitted, but we always find that a snowstorm is a very fine thing to improve our traffic, for generally speaking, whenever a snowstorm has taken place, our traffic has increased at least 50 per cent. On the occasion of the great snowstorm of January 19th, 1881, the messages at the central station, which averaged 40,000 a day, sprang up to 60.471.

With regard to submarine telegraphy, I have only to refer to the map for you to form some idea of the enormous network of telegraphs that extend all over the world, and which has brought the uttermost parts of the earth into intimate union with London. We have now no less than nine cables crossing the Atlantic—eight in the North Atlantic, and one in the South Atlantic. We have cables coming around the Peninsula, along the Mediterranean, down the Red Sea, across the Indian Ocean, away through the Archipelago to Australia, and from Australia to New Zealand. From Singapore they go northwards through Hong Kong to Japan, and away through China and Russia back to England. We have wires coming down through the West Indies to the Gulf of Mexico, and connecting the West Coast of America. The result is, that there is scarcely a spot throughout the whole world that is not in intimate connection with England. To carry out this tremendous undertaking £30,000,000 have been expended, and there are no less than 80,000 miles of cable at the bottom of the ocean. I remember twenty-three years ago reading a Paper—my first Paper—before this Institution, and I ventured to promulgate the unheard-of doctrine, that we ought to make ourselves as acquainted with the bottom of the ocean as we were with the surface of the land. The President of that evening—not always distinguished for his courteous manner—gave me a very severe rebuff for daring to promulgate such an outrageous notion before this Institution. But, gentlemen, we have since sent ships to every sea. Her Majesty's ship "Challenger" has spent three years in surveying the depths of the ocean. She has found that there is "a life," and a real life, "in the ocean wave," and "a home in the rolling deep," and she has found that the deep "unfathomed caves of ocean" do bear "gems of purest ray serene," and she has brought back to us a knowledge, not only of the life of the ocean, but of the nature of the bottom, so that we can now say that we know more of the depths of the ocean than we do of the surface of many a continent on this globe. The result is, that cables are now designed to suit every depth and bottom, and the operation of laying a cable has become a simple matter. The Telegraph Construction Company who laid, not the last cable, but the cable, I think, of 1880, across the Atlantic, succeeded in laying it without any hitch, without any stoppage, in the incredibly short space of twelve days. Again, repairs of cables have become equally a simple matter. A fleet of twenty-nine ships is maintained in different parts of the world to keep our cables in order. The cables can be brought to the surface from any depth. The 1869 cable, of which I have a specimen here, was brought to the surface from a depth of 1,940 fathoms and repaired; that cable is now thirteen years old, and is working as well as on the day after it was laid. A cable in the Bay of Biscay has been picked up from a depth of 2,700 fathoms and repaired. I am therefore justified in saying that cables have become a solid property, and that their age, their estimated age, has increased considerably from what we took it some few years ago, namely, ten years, to certainly fifteen or even twenty years, and British capital-

ists are now justified in investing their money in such enterprises as this map displays, which I look upon as one of the greatest glories, if not the very greatest glory, of British enterprise.

We have some remarkable accidents in cables. You would scarcely conceive it possible that a cable could be destroyed by fire; yet we have had an instance where a cable was destroyed by fire. Some idle boys lit a bonfire on the beach immediately over the shore end, and the heat melted the gutta-percha and broke it down. We have had a cable broken by a bull; a mad bull rushed vehemently down the streets of Yarmouth in the Isle of Wight, into the harbor and got entangled amongst the wires there, and broke a submarine cable. In the Indian Ocean a cable was found broken, and when they went to repair it they brought up a whole whale. The whale had got entangled in the wire. The whale was dead, and so was the cable. Again, we find little treacherous animals attacking wires, such as teredos, zylophaga, limnoria, and a few other little creatures of that character, which bore into the cable, reach the copper wire, and break down the cable, and the result is, that strenuous measures have to be taken to protect cables from these villainous opponents. The cables that are now laid in depths liable to the action of these teredos are armor-plated; the gutta-percha is coated with a thin taping of brass, and microscopists and physicists have yet to find a little wretch that will pierce its way through brass. Now, gentlemen, I ought to have shown you certain specimens of cable; but you all know what a submarine cable is, and as there are plenty of specimens before you, for which I am indebted to the Telegraph Construction Company, the Gutta-Percha Company, the Silvertown Company, and others, you will see there, in various forms, the character of the conductor now in use.

I have shown how electric currents are conveyed from place to place. I want now to show how we can utilize these currents at distant places to appeal to the consciousness. An electrical signal can appeal to the consciousness, either through the eye, or through the ear. If the atmosphere of this room will only behave itself, I will show how we utilize one fact of electricity to produce effects; but let me assure you, that the vagaries of that needle before me at the present moment, are not due to electricity; they are due to certain currents of air that are flying about the room. However, perhaps I may be able to eliminate from the motion due to the currents of air, the motions due to electricity. I want to show you that whenever a wire conveying a current of electricity, passes in the neighborhood of the magnet, it causes that magnet to take up a position at right angles to the wire. This is the main and simple fact upon which most of our early telegraphs were based, and also upon which most of our present measuring apparatus are founded. Now this gutta-percha wire passes immediately over that magnet, and we have a battery underneath. When I bring these two wires together, you will observe the effect (illustration). It was not air, it was a current of electricity which produced that effect, and I will make him go back again. You will see that when I bring these two wires into contact, I produce a deflection of that needle. Well, that is the simple fact; but it will show, perhaps, better on these little instruments (single-needle telegraphs) before me. When I move this handle, I send a current of electricity around the magnet inside there, and I produce, as you see, an effect. Now, when I send the current in the other direction, I produce an effect on the other side, and then, by combining these two facts in different orders, we are able to form an alphabet, and convey words by spelling each letter—the letter A is that, B is that, and so on throughout the whole alphabet. The first and earliest instrument was this. It is not a Greek temple; it is one of Cooke and Wheatstone's original double-needle instruments—very pretentious in its appearance. In its day it was most useful. I can remember the time very well when, in order to make these needles work, we had to perch a little messenger boy astride on the top of this Greek temple, with a large magnet in his hand, in order to keep the needles steady. In the progress of scientific thought, the causes of that vibration, that interfered so much with our reading were speedily found out and eliminated, and the result was the double-needle instrument was converted into the

particular form that is known as the single needle which is found now in every railway station. There are in the Post Office no less than 3,791, and in the railway service of this country, 15,702; so that we have 19,000 of these little single-needle instruments in this country, carrying on the traffic of our railways and conveying wishes and thoughts from place to place.

The second effect that is utilized for telegraphic purposes, is the simple fact, that if you take a mass of iron and surround it with wire, sending a current of electricity through the wire, you convert that piece of iron into a magnet. Without electricity, I may move this piece of iron amongst those nails, and the effect is *nil*; but with electricity, the effect is very different, the nails are attracted and cluster about each other in a very striking way, but the moment I take the current away the effect disappears. You see the moment I transmit the current through the coil, we have magnetism strong; the moment I take it away the magnetism ceases.

In order to produce sounds, in order to produce effects, it is only necessary to imitate the motion of the hand. Supposing I want to strike that bell, I merely give a little joint movement, and I strike that bell and produce some sound. Now let me put my magnet there, and in front of that magnet I place a little bar of iron jointed, instead of the rough and uncouth nails, and you will see that whenever I send my current through the coil I produce an attraction. You see how easy it is to put on that iron bar a little hammer, and in front of it something that will emit sound, and there I produce a sound. By the bye, let me show you how to make a bell ring, because there are many of you interested in railways, and you will see how simple it is to produce the sound of a bell. You see, by the effect of currents, I simply reproduce the movement of my wrist. Those two effects that I have shown you are the basis of all telegraphs, or nearly so, that exist at the present day. Either we avail ourselves of the deflection of the needle, or we avail ourselves of the production of magnetism. We have the simplest form of telegraphs known in Wheatstone's A B C, of which there are 4,398 in use in the Post Office. There the simple rotation of a needle propelled by currents, causing it to dwell opposite the letter that you want to indicate, enables you to spell out a message; you simply rotate a handle and work some finger-keys, and the result is you are able to cause a little index to dwell opposite any letter of the alphabet you wish to send, and any child or any old woman can work it; but the effect is rather slow, and this instrument is gradually being replaced now by an instrument that will be brought before you the next time we meet, called the telephone.

Acoustic reading—reading by sound—is the advanced character of the telegraphs of the present day. We commenced with a slow and cumbrous double needle; we passed to the single needle, and about the year 1852 one or two various classes of apparatus were designed and devised by Mr. Henley, by Sir Charles Bright and his brother, and by others. Many companies were formed to carry these out; and when the telegraphs were bought by the State there was the survival of the fittest; the best adapted were selected, and the result is that at the present time we have the A B C for small stations; the single needle for bigger stations, and, where real business involving a skilled staff is required, we come to the acoustic instruments. One of the earliest is the "Bell," of the brothers Bright, and here we read by an alphabet formed of two sounds, differing in tone or pitch. That is one sound; that is another sound; and thus the alphabet is formed; so that you have the whole of the letters of the alphabet formed by a mere succession of sounds, each combination of sounds itself distinctly indicating its character as clearly as we say A, B, or C.

This system of acoustic reading has passed through several stages to the instruments we use at the present day. Morse invented the alphabet that is used. Morse's instrument was first employed in America; it came over to this country and to the Continent, and at the present moment, while there are 1,330 Morse instruments in use in England, there are over 40,000 in use on the Continent. The best form is that produced by the house of Siemens, where the characters of dots and dashes are imprinted in clear

ink upon a paper strip. Here is the paper strip, and the paper passes through this instrument, and the characters are depicted upon it in a way I shall show you presently. But it was very soon found that the dots and dashes that were made by a magnet like that, conveyed to a man's ear by their sound precisely the same idea that they conveyed to his eye by the marks they make; he could detect by the ear precisely what was wanted, and sound-reading came in not by invention, but by accident, or by a combination of the two. The instrument broke down; the little magnet continued its work, and the skilled clerk was able to carry on the work by his ear. The result has been that these instruments are simplified in their character; they are more expeditious in their action; they are more accurate, and the rate at which they work is simply the speed at which a man can write. The sounder is an importation from America, where scarcely any other form of instrument is used. In 1869 there were none in England, now there are 2,000. On the Continent there is scarcely one! Now we have got wires brought into this room; one I hope goes to Birmingham; the other may go—I don't know where, but we shall find out directly.

(Mr. Preece then told his assistant to ask for an alphabet from the Central Station. The alphabet was sent so that every one in the hall could hear it.)

You have seen, from the actual operation of reading by sound, how the alphabet is made up by dots and dashes. Although I said that that instrument is distinguished by its great accuracy, nevertheless I do not pretend for one moment to say that it is not inaccurate. Errors are inherent to telegraphy, and, do what we will, errors cannot be avoided. The personal equation enters very largely into telegraphy. A telegraphist is in the position of not seeing what he writes, and of not hearing what he says, and therefore he is in a very much worse position than we who see what we write, and hear what we say. And yet how many of us are there in this room who can write for a very long time without making a mistake, or who write a signature that is legible all over the world? In order to prepare myself for this lecture I communicated with every railway company in England. I was laboring under the delusion that my name was pretty well known amongst the railway world at any rate, but I found I was mistaken when I got a letter back addressd "W. H. Keene." It came back addressed "W. H. Green;" it came back addressed "W. H. Greer;" but the worst blow of all was to receive this letter addressed "W. H. Piller!" Now if an accurate and beautiful writer like myself has his signature so mistaken, you cannot fail to comprehend why telegraphists make mistakes sometimes. The mere loss of a dot may cause a mistake. For instance—you have all heard the story perhaps, but it is so good that I cannot resist telling it again: a party of young ladies from a school went to a certain place, and the schoolmistress was very anxious to know of their arrival, so the message was sent, "Arrived all right;" but the schoolmistress received the message, "Arrived all tight!" Now, gentlemen, when the mere loss of a dot occasioned that, you can readily understand how mistakes arise. There was another one that perhaps many of you here may understand. A message was sent, "Five fathoms of eight feet will do;" it was received, "Five fat sows of eight feet will do." Now, there is scarcely any difference whatever between "fathoms" and "fat sows" except a short pause. I could go on all night telling you these stories, but I have come not to amuse but to instruct you. I want to point out that the progress made in the applications of electricity to commercial purposes has been followed by progress in the character of the apparatus used, in the mode of working, and in the efficiency of the staff employed. Careful specification, exact measurement, sound workmanship, and rigid inspection, have given to telegraphic apparatus a character that I defy any other workmanship in the world to surpass. Cheap and nasty are synonymous terms in telegraphy. There are on this table instruments that, in construction, in design, and in workmanship, will bear comparison with the finest chronometers that were ever produced. The progress of telegraphic apparatus is an admirable example of growth by cultivation, of evolution by scientific selection, and of the survival of the fittest.

We have introduced various modes of working, but of all the machines the one that is used to the greatest extent on the Continent, and which in design and workmanship will equal any of them, is the beautiful type-printing apparatus of Professor Hughes. The instrument is used exclusively by the Submarine Company between England and Europe, and as an international instrument all over Europe. It is worked direct between Paris and Constantinople. There are three or four thousand of these instruments at work. We have one here, and I will ask that the alphabet be sent. Now, in this instrument we have letters and words reproduced in bold Roman type, and doubtless many of you who communicate with the Continent receive messages printed in this bold and legible character. After the lecture is over we will have many slips printed, and you will have the opportunity of seeing it in working order. I should like to have spoken of the instruments used in our exchanges and clubs to record news and the price of stocks, and I should like to have spoken of Sir William Thomson's beautiful siphon-recorder that is used on all long submarine cables; but the clock in front of me tells me that I am like many trains in this country—rather lagging behind by time; so I must resist the tendency I have to dwell on many of these things, and run rapidly through my programme,

In the instruments I have shown you, and in the mode of working you have seen, we have what is called simple telegraphy. I want to show you how we can work duplex, that is, instead of sending one message in one direction we can send two messages at the same time in opposite directions. This is one of the simplest of the phenomena that we use, and one that I have very strong hopes of being able to make you understand. For that purpose I have here two instruments, and they are in connection with each other, so that when I move one needle the other is deflected; when I send a current of electricity from here to there I move both these needles; when Mr. Cooper sends a current of electricity to me he also moves both those needles. Now I want to make use of this simple fact, that when I send a current of electricity to the other station at the same moment that he sends a current of electricity to me, these two currents neutralize each other, and nothing whatever passes upon the wire. Many people imagine that in duplex telegraphy currents pass each other. Nothing of the sort. Nothing whatever passes; we utilize the fact that the wire is neutralized and that nothing passes. When I move my needle I want to so arrange my needle that my own current shall not affect it, and for that purpose the needle is surrounded with two wires, through one of which the current goes in one direction, and through the other the current goes in the reverse direction; so that if I make those two currents exactly equal I shall obtain neutrality for my needle—now you see I have not got neutrality—but by putting resistance in I at last get to a point when my needle is not affected but the other one is. I will ask Mr. Cooper to adjust his in the same way. Those two instruments are now so adjusted that while he is working his, mine only is affected, and while I am working mine his only is affected. Why is this? Because I have two currents going around my needle in opposite directions, and he has the same; but if we check or neutralize one of those currents the result is that the other will act. Every time he moves his handle I may move my handle: we do not affect each other in the least. I keep sending dots, he sends something else, and the result is that he can cause my needle to move as he pleases, and I can cause his needle to move as I please, and it is simply owing to the fact that we utilize the neutralization of currents to produce effects at our own station. We have a wire here that goes to our central station, and I hope to be able to show this system of duplex telegraphy working in actual operation. We have got Birmingham here. You see duplex working between this room and Birmingham. [A message was sent while one was being received.]

When you send messages in opposite directions at the same time you have duplex working; you can, however, send two messages in the same direction, though you cannot send two currents in the same direction at the same time. You can, however, send currents which shall vary in direction, and currents

which shall vary in strength, and you can have one instrument that will record its marks by any change in direction independent of strength as well, or you can change the current in its strength whether it goes in one direction or the other, and you can make an instrument respond to changes of strength independent of direction; so that you have one instrument responding to change of direction, and another instrument responding to changes of strength.

That leads me to duplex working—two messages going in the same direction at the same time. Well, if you can have two messages going in the same direction at the same time, and two messages going in opposite directions at the same time, the result is you have quadruplex working, or the method by which four messages are sent upon one wire at the same time, an importation from America where this mode of working was made practical. [Quadruplex working with Birmingham was now shown.] Of course, in absolute telegraph work we have all the morning before us to adjust, or at any rate before business commences; but for illustration in this hall we could only get the wire after seven o'clock. Now, you will notice how we speak to a station, although it is 115 miles away, as though it were in the next room. Space by telegraphy is absolutely annihilated.

You have before your eyes what is taking place every day in England and in America, on a great many circuits. In England we have thirteen of these circuits, and some of them are worked in a curious way. Here [drawing on the board] is West Hartlepool, here is Middlesbrough, here is Leeds, here is London. We have one wire between Leeds and West Hartlepool, another wire between Middlesbrough and Leeds, another wire between Leeds and London. Now that wire works quadruplex between London and Leeds, duplex between Leeds and Middlesbrough, duplex between Leeds and West Hartlepool. West Hartlepool works duplex to London, Middlesbrough works duplex to London, and both those stations can work duplex to London at the same time and on the same wire.

But beautiful as this mode of working is, and greatly as it has increased the capacity of our system, it does not compare in design, in efficiency, or in adaptation to what I am going to bring before you now, viz., Wheatstone's automatic-working system. On this we utilize Morse's alphabet. Here mechanism supplants manual labor. There (on the quadruplex) you saw the clerks working, and the rate of their working was dependent upon the rate at which they could key, and that varies from 20 to 30 words a minute, in fact we may take the average number of words sent by a good telegraphist per minute at, say, 30; but when we replace manual labor by mechanism, we can increase that limit to almost anything, and I will show how we are receiving work upon our wires at the present moment at the rate of from 200 to 250 words per minute. From 1870 to about 1873 or 1874 the rate of increase of wire and of messages was about the same, but then there was a departure. We commenced to understand automatic working and duplex working, and during the last five or six years we have carried it to such a pitch that while the mileage of wire has increased about 100 per cent. messages have increased over 230 per cent.; so that by the teachings of experience and by the application of scientific thought, we have succeeded in so increasing the capacity of our wires that they have been able to meet the tremendous increase of business. I will show you how this is done. We have a wire here. We prepare our messages by mechanism, and instead of sending them by hand they are punched on paper. Here is an alphabet punched on paper; it is like the preparation of paper for lace in the Jacquard loom, and this perforated paper will be passed through a transmitter. A clerk can only punch at the rate of 30 to 40 words per minute; the instrument can send this punched paper at the rate of 200 to 250 words per minuute, so that the instrument is able to take off the work prepared by five or six clerks. Now I want to show you how the news of this country is transmitted. We have here London [drawing on the black board], Leeds, Newcastle; we have there Edinburgh; we have there Glasgow; we have there Dundee; we have there Aberdeen, and we have there the Institution of Civil Engineers. Now, a strip is punched by

several punchers; it is put into the transmitter at the central station, as you see it there [pointing]. Now the strip is going through the instrument, and at the same moment a similar strip is sending its messages to Leeds, to Newcastle, to Edinburgh, to Glasgow, to Dundee, and to Aberdeen, and every one of those stations, as well as on other wires, Liverpool, Manchester, Birmingham, Bristol, Newport, Cardiff, Plymouth, Exeter, and in other directions other stations, is at the present moment being filled with exciting news, by means of that apparatus that you see before you, and this is going on at the rate of 200 words a minute; so that we have I cannot tell how many writers, at how many stations being supplied by this process. We have twenty-eight of these news circuits at work. And that the process is appreciated, if anything can be appreciated by our press, is evident by the fact that instead of the 5,000 words sent per day that were supplied to the newspapers when the telegraphs of this country were in the hands of private companies, there are 934,154 sent now, and last year there were no less than 340,000,000 words suplied to the press; and still they are not satisfied. In 1871 the number of words delivered in one week was 3,598,000; in 1882 it became 6,557,000! This work is done at an absolute loss. The Government has to pay a considerable subsidy towards providing the newspapers of this country with their daily pabulum of news.

One of the great steps in advance, one of the means by which this tremendous business is done, is this system of automatic working. Five years ago we were only able to transmit 147 messages per mile of wire, now we transmit 256, the ratio of 147 to 256 indicating the rate of improvement in the capacity of our wires. One great improvement that we have introduced is fast speed repeaters. This is a repeater. It is an exquisite instrument in itself. It is very complicated, but very simple in its working; and the result of the introduction of these instruments is to render the rate of working on long circuits the same as the rate of working on short circuits. We have eighty-one of these repeaters in use. By the insertion of a repeater at Leeds, and another at Edinburgh, we are able to maintain that speed of 200 words a minute to all those stations shown on the board, and the value of this repeater is such that there is no more difficulty in sending at a fast rate (I will not say 200 words a minute, but 100 words a minute), between London and Edinburgh, than there would be in sending between London and Calcutta.

On the Continent efforts have been made by Meyer and Baudot to increase the capacity of wires by the application of another principle, called multiple working. A unit of time is divided into four or more sections, and each section apportioned to a pair of telegraphists at the two ends of a circuit—one to send, one to receive. Each section of time allows one letter to be sent, so that four messages can be in the act of transmission at the same time, though there are no simultaneous signals, as in the quadruplex apparatus. A gain of speed is obtained with type-printing instruments, but the game is not worth the candle, for the additional apparatus needed is complicated and delicate. Its success has not been marked, though an immense amount of talent and ingenuity has been expended on its development. The exquisite mechanism of the Baudot apparatus was one of the features of the Paris Electrical Exhibition of 1881.

With great grief I pass over notes involving some interesting matter that I cannot possibly bring before you, but which you may have an opportunity of reading some day or other. Although statistics are very dry in themselves, statistics are most interesting as showing the progress made in this country and in the world in telegraphy. I have been to America, I have been on the Continent of Europe, and I can say this without hesitation, that all these countries have a lesson to learn from us. People are very fond of bringing before us America as an example. We have taken many lessons from America, but America has been very glad to take us as an example also, and America is now applying on their principal wires in the Western Union system, not only this apparatus, but we have had the pleasure of selecting and sending out experts to show them how to work this system. We use the telegraph more in England than they do in America, and our tariff

is less. In England every hundred persons send 91 messages, while in America they send only 77. We send ten times as much news for the press. The amount of work done in England is indicated by that table, but I can give you a fact interesting in itself. I remember the time when we thought 1,000 messages a day a tremendous business in our central telegraph station. On August 4th, 1882, there were not 1,000 messages sent, but 92,017. Gentlemen, I will not occupy your time by giving you many figures. The traffic of the Eastern Telegraph Company has increased in equal proportion; in 1871 they sent 186,000 messages; in 1881 they sent 720,000; and the same argument is equally applicable to them—that they have improved their rates of working as we ourselves and other organizations have. The cable companies do an enormous business, and by the way in which they do their business they have revolutionized trade; they have completely altered the mode of transacting business throughout the world; the home trade of this country has been extended to all quarters of the world, and the old middleman is gradually disappearing. In foreign countries, too, we have some remarkable instances of progress in telegraphy. Japan, for instance, last year transmitted no less than 2,223,214 mesages, and of these more than 98 per cent. were in their own native tongue; while contiguous China does not possess a single telegraph of its own at the present day, as far as I am aware. There were in 1880, amongst the administrations who had joined the International Bureau of Berne—

Lines of Telegraph..	268,000 miles.
Wire	768,600 "
Instruments.....	53,144 "

The development of railways in this country has necessitated a corresponding increase in the telegraphs required to ensure the safety of the traveling public, and while 27,000 miles of wire in England, Scotland and Wales, were used for that purpose in 1869, at the end of December, 1882, the total had increased to 69,000 miles, equipped with 15,702 instruments, against 4,423 in 1869.

TRANSMISSION OF POWER BY BELTING.

By EDWARD SAWYER.

From the Proceedings of the Society of Arts.

THE transmission of power by belting was intelligently investigated by Gen. Morin, the well-known French physicist, some forty years ago. I have not looked back of that for any publication on the subject. Subsequent writers of the better class seemed to have followed Morin. Other writers have published theories and rules which are clearly erroneous, probably without knowing anything about Morin's investigations. An empirical rule, however erroneous its theory may be, if deduced from a correct practical example, will of course work back correctly to the same case, and approximately to others which are nearly like it; but when the conditions differ widely from that, the result may be grossly erroneous. Writers of another class have published a great number of statements of practical cases, giving the widths and speeds of belts driving certain machines, sometimes accompanied with guesses more or less wild as to the power conveyed, satisfactorily or otherwise.

If I pull or push on a pulley strongly enough to move it, the amount of work done depends on the force and on the distance moved by the point of application in a given time. A belt does its work, of course, by transmitting a pull from one revolving pulley to another. Tnere is no difficulty in estimating its velocity from the diameter and rate of revolution of either of the pulleys, but the amount of its pull is not so easily ascertained.

In the use of pulleys and belts we find it is necessary to have more or less tension in the following or slack side of the belt to prevent slipping. Obviously this tension makes a back pull on the driven

pulley and balances an equal number of pounds of the pull of the leading side, and the difference of the pull of the two sides of the belt is all that is available for driving. And here we strike the principal difficulty of the whole matter. We must ascertain how much the tension or pull of the leading side can exceed that of the following side without causing slipping, with different kinds of surfaces and under different circumstances.

Morin proceeds as follows: He assumes, by implication, that the hold of a belt and pulley is due to ordinary friction produced by pressure, and that it is practically the same whether the belt and pulley are at rest or revolving together. The next step is to ascertain the coefficient of friction for various kinds of pulley and belt surfaces. For this purpose he used plane surfaces as more convenient for experiment than pulley rims, and presumably giving the same results. Neglecting the rigidity of the belt, he demonstrates by the integral calculus what the hold of the pulley will be for different frictions. From his experiments he found a coefficient of friction of 0.28, whence he deduces that 1 pound pull on the slack side will hold 2.41 pounds on the tight side; or, to put it in a way which I think brings out the controlling ideas better, 1,000 pounds on the tight side will be held by 415 pounds on the other side, leaving a force of 585 pounds for moving the pulley.

But while Morin's principles seem to be correct, his statements about the coefficient of friction are too brief and indefinite, and the value which he adopts for the case of leather and cast iron is greatly in excess of what I find. He does not say whether he took the pull required to start the slipping, or only that required to keep up the motion after starting; the latter would seem to be the only safe thing to depend upon. It seems possible that he may have used iron surfaces as they came from the foundry, and perhaps he had a different quality of leather from that now used.

The idea that the hold of the belt is due to friction caused by the pull of the belt seems to me to be a reasonable one, and it agrees with all the facts in the case so far as I know. We see that there must be tension on the slack side of the belt to maintain the hold of the surfaces on each other. For any given conditions and materials, the amount of this back tension must be proportional to the hold required, that is, to the number of pounds which the driving surface has to pull on the other to do the work.

The coefficient of friction is found to be independent of the intensity of the pressure by experiment both on flat surfaces and on pulley runs. Here are two cast-iron pulleys, eight inches and fifteen inches in diameter, both having surfaces finished and polished in the ordinary way, and just alike as far as known. We clamp them on a stand, hang different kinds of straps on them, and find what weight on one end will just suffice to stop the sliding caused by a heavier weight on the other end. Numerous trials show that the average hold of the belts is as good on one pulley as on the other, and that the smaller weight is the same fraction of the larger one on both pulleys, but of course not the same for different kinds of belts.

The notion is very common, and it is held by many intelligent persons, that a belt will hold more on a large pulley than on a small one. So far as can be learned from experiments on pulleys at rest, this is one of the many cases where people know things that are not so. By the unanimous verdict of competent experimenters, this notion is exactly the reverse of the truth, and we must eradicate it altogether from our minds before we can have a correct understanding of the subject. If we increase the size of a pair of pulleys without changing the speeds of the shafts (or the number of revolutions per minute), they will travel faster and do more work in the same ratio, the tension and hold remaining just the same as on the smaller pulleys. It is absolutely essential that we should keep in mind the two factors of power—*speed* and *force*—and not credit one with what is due from the other. But here we have run into the question of whether the hold of the pulley and belt are the same when they are revolving together as when at rest. Doubtless the jerking and jumping due to variations in the belt and irregularities of all kinds favor slipping, but in well-arranged belt transmissions the loss of motion between driver and driven is found to be very slight, which seems to indicate that we

need not make much allowance on this account. Centrifugal force tends to throw the belt off from the pulleys, and hence diminishes the hold. The amount of this will vary greatly with the size and speed of the pulleys, as shown by the following estimates:

A pulley of one foot diameter at 150 revolutions loses .006—ordinary machine pulley.

A pulley of three feet diameter at 300 revolutions loses .047—ordinary counter pulley.

A pulley of eight inches diameter at 1,500 revolutions loses .116—picker beater-pulley.

A pulley of four feet diameter at 400 revolutions loses .148—main pulley.

A pulley of five feet diameter at 400 revolutions loses .186—main pulley.

From which we see that it is unimportant in ordinary cases; but that some allowances should be made for it in the case of quick-running blowers, circular saws, picker beaters, etc., and rather more in case of pulleys four feet in diameter and upwards, making four hundred revolutions per minute, which is near the maximum for main shafts in large modern mills. But, then, quick speeds have come up almost entirely since Morin's time.

If the running belt forms a vacuum between it and the pulley, this tends to offset these losses. I know of nothing else which is material on this question. Hence, I suppose that in ordinary cases we may reckon the hold to be about the same in running as at rest. But one must not overlook the allowance for centrifugal force at very high speeds.

Experiments on the hold of pulleys in motion would be interesting and valuable if carefully and skillfully made. When a belt is moistened with some oily substance we may get some advantage from fluid adhesion; on the other hand, the lubricating effect may offset it. When a belt is coated with grease so that the leather does not touch the iron, we have another kind of surface, which may hold better or worse than leather. Sometimes a belt gets glazed over with oil and grime so that it has a very poor hold on the pulley.

If the belt is overworked, too much of the tension is taken out of the following side and put into the driving side, and, as soon as the disproportion between them becomes too great, slipping results. Of course the belt can be tightened, perhaps enough to enable it to do its work temporarily, but if it is overworked, it will show it by stretching and slipping again. One remedy for this is to put on larger pulleys, and thus run the belt fast enough to do the work with the pull which it will stand satisfactorily. Another remedy is to put on a belt wide enough to stand the requisite pull at the present speed. The superior efficiency of the wider belt is due to the fact that it has more stock and will stand more pull than the narrow one, and not at all to the fact that it covers more surface on the pulleys.

Many people do not understand this, but think a narrow belt has to pull harder than a wide one to do the same work, thus causing more friction and wear on the bearings. Some very skillful manufacturers labor under this misapprehension. The total pull is the same, but the pull per inch of width of course increases as the width of the belt diminishes; hence the narrow one will stretch the faster—if too narrow, it will soon become slack, and slip; if a belt runs a long time without doing this, it proves that it is large enough for its work. We can double the stock in a belt, and so double its efficiency, by doubling the thickness, without any increase of contact surfaces on the pulleys. But usually it is better to increase the width and speed of single belt till the pulley reaches somewhere about $36'' \times 6''$ before putting on double belts.

We come now to the question of amount of back pull necessary to prevent slipping. Perhaps the most satisfactory method of proceeding will be to take up the direct experiments first.

On polished cast-iron pulleys, hard, new leather belts require fully 75 pounds to hold 100 pounds; but usually the ratio is between 60 and 70 per 100, corresponding to co-efficient of friction from 0.17 to 0.12. Pieces of old belting, and thoroughly oiled, averaged better; some trials went as low as 56 per 100. Rawhide belting appears to hold very well, giving an average a little over 60 per 100. Rubber belting averaged a little under 60 per 100.

The 12-inch pulley with an old, oily,

leather lagging, just as it came from the mill, required not over 20 pounds per 100 pounds with the old leather belt. A pulley turned, but not polished, required about 65 pounds per 100.

If these results are correct, or nearly so, it is not safe to reckon on transmitting more than one-third or one-fourth of the pull on the tight side of an ordinary leather belt to a smooth iron pulley with 180° of contact. A usual method of reckoning in this country has been that a one-inch single belt running at one thousand feet per minute with 180° of contact will transmit one horse-power without any rapid deterioration. This requires much more than the proper maximum strain as given in standard books. Claudel says that a belt will run a long time without stretching at one-fourth of a kilogramme per square millimeter of cross-section, or about 55 pounds per inch of width for single belting.

The proper width for belting to convey a given amount of power may be calculated by the following expression, in which the constants are such as correspond to the best practice:

For double belts:

Width, in inches = 600 × H. P., divided by speed of belt in feet per minute; or 191 × H. P., divided by number of revolutions per minute × diameter of pulley in feet, H. P. being the horse-power which is to be transmitted.

For single counter-belts: twice as wide as double belts.

For machine belts:

Width = 1,500 to 2,000 × H. P., divided by speed; or 477 to 636 × H. P., divided by number of revolutions × diameter of pulley.

In these cases smooth iron pulleys are supposed to be used.

A belt under tension binds around the pulley, and will press against it and produce friction by an amount which will depend upon the amount which the belt wraps around the pulley. This pressure or hold of the belt may be calculated mathematically. The most satisfactory solution of the problem is by the use of the integral calculus, but an approximate solution is readily made without the calculus, and the results of such a solution were given upon the blackboard. By this it was shown that when a belt having a coefficient of friction of about 0.10 goes half-way round a pulley, a little more than one-quarter of the pull on the tight side is communicated to the pulley, and the remainder must be left in the slack side to prevent slipping. Similarly, when the coefficient rises to 0.44, three-fourths of the pull on the tight side may be communicated to the pulley, leaving only one-fourth on the slack side. If the belt does not wrap the pulley for 180°, the practical rule is that the width of the belt should be increased in nearly the same ratio that the angle of contact is diminished from 180°. The stiffness of the belt may slightly diminish the hold on the pulley, but only in case the pulley is quite small. Variation in area of contact with same total pressure does not vary the hold, but slight changes in the condition of the surfaces may considerably change the co-efficient of friction. Some erroneous formulæ, arising from a disregard of these facts, were then discussed.

Uniformity of thickness of belts is important at high speeds. Double belts should be limited to one thirty-second of an inch variation. Rubber belts possess an advantage in this.

Overstraining of belts from careless management causes unnecessary wear of belts and machinery, and great loss of power by friction. The importance of careful adjustment of band strains has of late years received considerable attention in spinning-frames, and its importance deserves more general recognition.

At a meeting of the Lower Rhenish and Westphalian Engineering Association, held a short time ago, Herr Gleim gave some detailed particulars as to the use of steel in the construction of bridges. He alluded to the fact that American engineers attach more importance to the extensibility of steel than to its possessing a high degree of strength. In the standard bars used for the tests—8 in. in length—the former quality must represent 15 to 10 per cent. before a fracture takes place. The productions of American steel manufacturers have now, he remarked, a strength of 29½ tons to 35½ tons per square inch, while the limit of elasticity lies between 16 tons and 17 tons approximately. He further stated that from the fact of the limit of elasticity of steel being somewhat over the half of its ultimate strength, while in iron it is, he says, much less. American technical authorities claim for steel an advantage over iron in greater proportion than the difference between the relative ascertained ultimate strengths of the two substances.

THE RELATIONS BETWEEN THE SIZE, SPEED, AND POWER OF MARINE ENGINES.

By RICHARD SENNETT, Chief Engineer Royal Navy, Memb. Inst. M. E., &c.

From the "Journal of the Royal United Service Institution."

I NEED scarcely remind the members of this Institution that the relations between the size, speed, and power of marine steam-engines are not absolute and unchangeable, but that they have been continuously varying during the progress of steam navigation. In fact, we may say, that advance in marine engineering has resulted from, and been marked by, the modifications made from time to time in these relations.

The elements on which the power of any steam-engine depends are the dimensions of the cylinder, the speed at which the piston moves, and the pressure of steam employed. In general terms the power may be taken to vary as the *size* × *speed* × *pressure*. It will be seen from this, that the relations between the size, speed, and power, are directly affected by the pressure of steam at which the engine is worked.

One of the most interesting and remarkable features in the progress of steam navigation has been the successive increments in the working pressures of steam used. The rate of increase may be roughly sketched as follows:—In the few steamships that existed prior to the year 1840, the usual working pressure was 4 or 5 lbs. per square inch. Between 1840-50 tubular boilers were substituted for the old flue boilers, and the working pressures were from 10 to 15 lbs. per square inch. From 1850 to 1860 the ordinary working pressure was 20 lbs. per square inch. Between 1860-70 surface-condensing engines became general for marine purposes, and were worked, as a rule, with steam of 30 lbs. pressure. The introduction of surface condensation, by which system the boilers are fed with fresh water, enabled high steam pressures to be carried with safety in marine boilers; and since 1870 compound engines have become almost universal for steamships. These were at first worked at 60 lbs. pressure. The pressures have gradually increased from 60 to 80, 90, 100, and in some recent examples to 125 and 150 lbs. per square inch. The ordinary working steam pressure in marine boilers at the present day may be taken at from 90 to 100 lbs. per square inch, and it is probable that still higher pressures may be used before long.

The increase in the working pressure of steam has produced two effects:

1. Reduction of the expenditure of coal; which is perhaps the more important, for this, and this alone, has rendered steam navigation for long voyages possible.

2. Reduction of the weight and space occupied by the machinery; this, from many points of view, especially for war-ships, is scarcely, if at all, less important than the reduction in the coal stowage.

These two divisions are so closely allied that it is somewhat difficult to deal with one without referring to the other. The subject of economy of fuel, however, important as it is, does not exactly come within the scope of the present paper; and I therefore propose to confine attention, as closely as possible, to the consideration of the reductions in size and weight of engines of a given power, that have been made, from time to time, by increasing the working pressures of steam and speeds of piston.

This is one of the principal problems with which marine engineers have to deal, and much progress has been made in its solution during recent years, and in connection with the machinery of ships intended for purposes of war. In war-ships, reduction of the space and weight required for the machinery may, in many cases, be of even more importance than reduction of coal expenditure. Although it is desirable that war-ships should be self-supporting for as long periods as possible, they are not often required to steam long distances at high speed, which is the normal condition of service in the Mercantile Marine, in which, therefore,

economy of coal consumption is, of necessity, the first consideration.

In most cases, however, we shall find that the same measures that have produced economy of fuel, have also enabled the space and weight required for the engines to be reduced at the same time, particularly at the beginning of the upward rise in the steam pressures. It is however possible that we may reach a point at which the increase in working pressure, though increasing the economy of fuel, will not permit of any reduction in the space and weight required for the machinery, so that the only gain in this direction would be that due to the reduced quantity of coal required to be carried. It is also conceivable that, by-and-by, a point may be reached at which further increase of pressure would not result practically in any reduction either in space or weight required for the machinery (including bunkers), or in the coal expenditure. I think, however, we are scarcely within measurable distance of that position yet.

The effect of the increase in the working steam pressure is to enable a given power to be obtained with a cylinder of smaller diameter, and thus to reduce the size and weight of the engines. The volumes of the steam-pipes and of the steam-spaces in the boilers may also be reduced, because the *relative volume* of the steam is decreased, that is to say, a given *weight* of steam at the higher pressures occupies less space than at the lower pressures. For example, at a pressure of 5 lbs. above the atmosphere 1 lb. of steam would occupy 19.6 cubic feet, at 20 lbs. pressure 11.6 cubic feet, at 60 lbs. 5.7 cubic feet, and at 100 lbs. pressure only 3.8 cubic feet. The boilers, steam-pipes, &c., can be further reduced, in consequence of the collateral advantage gained by the use of high pressure steam, viz., that *less weight* per I.H.P. is required, in consequence of the more economical working of the engines. All these parts may therefore be reduced not only from the decreased *relative volume* of the steam, but also because the total weight of steam required to be generated is likewise diminished.

So far, we have referred only to the reduction in size and weight due to the increase in the working pressures of steam. This has, however, been accompanied by a considerable increase in the speeds at which the pistons of marine engines are worked, which has tended still further to reduce the weight and dimensions of the machinery. This increase of speed has, of course, to some extent resulted from the use of higher pressures; but I think, it must be largely attributed to improvements in design, and in the details of practical workmanship. In the earlier engines it was not considered safe to work the pistons at a much higher speed than about 200 feet per minute. From an old machinery specification, dated 1845, I extract the following:

The speed of piston for

ft.	in.					
4	0	stroke is not to exceed			196	feet per minute.
4	6	"	"	"	204	"
5	0	"	"	"	210	"
5	6	"	"	"	216	"
6	0	"	"	"	222	"
6	6	"	"	"	226	"
7	0	"	"	"	231	"
7	6	"	"	"	236	"
8	0	"	"	"	240	"

In modern marine engines of large power the piston speeds are often as high as from 600 to 700 feet per minute, and every effort is being made, by the use of improved workmanship and appliances, to increase the piston speed, with safety, to as great an extent as possible.

The relations between the size, speed, and power of marine engines may, perhaps, be most clearly illustrated by giving a brief sketch of the changes that have been introduced from time to time. In this comparison I have confined attention to the progress made in ships of the Royal Navy, for which the information is more complete and available than for the Mercantile Marine; and this will probably possess the greater interest for the members of this Institution. I think, too, we may safely state that the machinery for ships of war has, in all stages of the progress of steam navigation, represented the most perfect and complete type of marine engine of the day. It will, I think, be admitted, that the design of the machinery for ships of the Royal Navy has not only kept abreast of the times, but that, in many instances, it has taken the lead and initiated improvements which have considerably advanced marine engineering.

The information that can now be obtained about the earlier vessels is much less complete and exact than about the later vessels, for it is only within a comparatively recent period that the importance of keeping full and accurate records of all the particulars and performances of steam-vessels has been fully recognized. I have, however, endeavored to make the comparison as full and fair as possible, and although it must be considered to some extent incomplete and approximate, I think a few useful lessons may be learnt from it. The *size* of the engine has been represented by two particulars, viz., the cubic capacity of the cylinders, and the total weight of the machinery; the former giving a measure of the dimensions of the engines themselves, independent of the boilers and appliances.

The propeller used in all the earlier steamships was invariably the paddle-wheel, and the type of engine generally employed was that known as the *side-lever* engine, which may be regarded as the marine counterpart of the beam-engine so universally used at that time for land purposes. This engine possessed the advantages of having the pistons and rods, to a great extent, balanced by the pumps and rods and connecting-rod, so that the piston was nearly in equilibrum in all positions. The great length of connecting-rod was also favorable for the transmission of the power to the crank. The engine was, however, very heavy, and occupied much space for the power developed. The boilers that supplied steam to the earlier engines were those known technically as *flue boilers*, in which the heating surface consisted of the exterior surface of a winding flue that conveyed the products of combustion from the furnaces to the funnel. These boilers were excessively heavy and cumbrous, and suitable only for very low pressures of steam.

As an illustration of this type we will take the "Rhadamanthus," which ship was fitted with side-lever engines and flue boilers, by Messrs. Maudslay, in 1832. The nominal horse-power was 220, but the engines were capable of being worked up to about 400 I.H.P., or 1.8 times the nominal power. The load on the safety valves was 4 lbs. per square inch, and the speed of piston, at full power, 175 feet per minute. The cubical capacity of the cylinders was 168 cubic feet, so that only 2.38 I.H.P. were developed per cubic foot of cylinder. The total weight of the machinery was 275 tons, 1.45 I.H.P. being obtained per ton of weight.

The next step was the introduction of *tubular* boilers, in which a series of small tubes was substituted for the large winding flue; the boilers were thus made lighter and more compact, and the working pressures of steam were increased. Attempts were also made to reduce the space and weight required for the engines by the substitution of direct-acting for side-lever engines. There were many varieties of this type, one of the earliest being the well-known double-cylinder engine, fitted by Messrs. Maudslay, in the "Terrible" and several other vessels. This engine consisted of two cylinders side by side, the piston-rods from the two cylinders being attached to a single cross-head. In order to get sufficient length of connecting-rod, the crosshead was of peculiar form and passed down between the two cylinders, having a journal at its lower end, on which one end of the connecting-rod worked, the other end being attached to the crank-pin. The engines of the "Terrible" were completed in 1845, and were of 800 N.H.P. The I.H.P. was 1,905, or 2.38 times the nominal power. The pressure of steam in the boilers was 9 lbs. per square inch, the speed of piston 240 feet per minute, and the total weight of the machinery 607 tons. In these engines 2.1 I.H.P. were developed per cubic foot of cylinder, and 3.14 I.H.P. per ton of weight.

The simplest and most compact form of engine for paddle-wheels was attained by the introduction of the *oscillating engine*, which was adopted and perfected by the late eminent marine engineer, Mr. John Penn, with whose name this type is generally associated, though it was also used by other makers. In this engine the connecting-rod is dispensed with, and the piston-rod is connected directly to the crank-pin. The cylinders oscillate upon hollow axes or trunnions, through which the steam is admitted to, or exhausted from, the cylinders, so that the piston-rod may accommodate itself to the rotatory motion of the crank. As an example of this type we will take the

Ship.	Date.	Maker.	Description.		Load per square inch on safety valves.	N. H. P.	I. H. P.	I. H. P. / N. H. P.	Revolutions per minute	C	
			Engines.	Boilers.						No.	Diamet
					lbs.						ins.
"Rhadamanthus"	1832	Maudslay	Side-lever	Flue	4	220	400	1.8	17.5	2	55¼
"Retribution"	1842	"	4-cylinder, vertical	"	6	800	1,600	2	13	4	72
"Gladiator"	1845	Ravenhill	Vertical, direct	Tubular	11	430	1,023	2.38	15.5	2	79¼
"Terrible"	1845	Maudslay	4-cylinder, vertical	"	9	800	1,905	2.38	15	4	72
"Sphinx"	1846	Penn	Oscillating	"	7	500	1,180	2.36	16	2	82
"Buzzard"	1850	Ravenhill	"	"	20	300	834	2.78	20.5	2	64
"Magicienne"	1850	Penn	"	"	14	400	1,300	3.25	20.5	2	72
"Himalaya"	1854	Penn	Trunk	Lamb's patent flue	15	700	2,046	2.92	56	2	=77¾
"Doris"	1857	"	"	Rectangular, tubular	20	800	3,005	3.75	54	2	=82
"Galatea"	1859	"	"	" "	22	800	3,052	3.82	56	2	=82
"Immortalite"	1859	Maudslay	Return connecting-rod	" "	20	600	2,390	3.98	55	2	76
"Revenge"	1859	"	" "	" "	20	800	2,548	3.18	52	2	82
"Victoria"	1860	"	" "	" "	22	1,000	4,403	4.4	58.4	2	92
"Undaunted"	1861	Ravenhill	" "	" "	21.5	600	2,260	3.76	58	2	76
"Valiant"	1861	Maudslay	Return connecting-rod	" "	25	800	3,348	4.18	59	2	82
"Black Prince"	1861	Penn	Trunk	" "	24.5	1,250	5,571	4 45	54.75	2	=104¼
"Agincourt"	1864	Maudslay	Return connecting-rod	" "	25	1,350	5,913	4.38	53	2	101
"Ocean"	1864	"	" "	" "	22	1,000	4,243	4.24	58	2	96
"Northumberland"	1866	Penn	Trunk	" "	25	1,350	6,545	4.84	47.6	2	=104¼
"Crocodile"	1867	Humphrys	Horizontal, direct	" "	30	700	4,044	5.77	63	2	96
"Hercules"	1868	Penn	Trunk	" "	30	1,200	8,529	7.10	71	2	=118
"Inconstant"	1868	"	"	" "	30	..	7,364	..	74.5	2	=104¼
"Active"	1869	Humphrys	Horizontal, direct	" "	30	600	4,130	6.88	74	2	88
"Audacious" (twin screw)	1869	Ravenhill	Return connecting-rod	" "	30	800	4,834	6.04	75	4	77
"Swiftsure"	1869	Maudslay	" "	" "	30	800	4,913	6.14	68	2	98
"Volage"	1869	Penn	Trunk	" "	30	600	4,530	7.55	79	2	=86¼
"Invincible" (twin screw)	1870	Napier	Return connecting-rod	" "	30	800	5,180	6.48	81.6	4	72
"Vanguard" "	1870	Laird	" "	" "	30	800	5,384	6.73	73.9	4	72
"Devastation" "	1871	Penn	Trunk	" "	30	..	6,637	..	76.8	4	=80
"Thunderer" "	1872	Humphrys	Horizontal, direct	" "	30	..	6,271	..	77.5	4	77
"Raleigh"	1873	"	Return connecting-rod	" "	30	800	6,157	7.69	74	2	100
"Amethyst"	1872	Rennie	Horizontal, compound	High, cylindrical	60	..	2,310	..	98.5	2	(1 No. 55 (1 " 97
"Alexandra"	1875	Humphrys	Vertical, compound	" "	60	..	8,498	..	66	6	(2 No. 70 (4 " 90
"Dreadnought"	1875	"	" "	" "	60	..	8,206	..	67.13	6	(2 No. 66 (4 " 90
"Bacchante"	1876	Rennie	Horizontal, compound	" "	70	..	5,413	..	76	3	(1 No. 73 (2 " 92
"Inflexible"	1876	Elder	Vertical, compound	" "	60	..	8,485	..	71.5	6	(2 No. 70 (4 " 90
"Shannon"	1876	Laird	Horizontal, compound	" "	70	..	3,538	..	65.5	4	(2 No. 44 (2 " 85
"Temeraire"	1876	Humphrys	Vertical, compound	" "	60	..	7,696	..	78.75	4	(2 No. 70 (2 " 114
"Euryalus"	1877	Ravenhill	Horizontal, compound	" "	70	..	5,250	..	71	3	(1 No. 73 (2 " 93½
"Iris"	1877	Maudslay	" "	" "	65	..	7,714	..	97	8	(4 No. 41 (4 " 75
"Nelson"	1877	Elder	Vertical, compound	" "	60	..	6,246	..	80	4	(2 No. 60 (2 " 104
"Northampton"	1877	Penn	Vertical, composite	" "	60	..	6,010	..	84	5	54
"Carysfort"	1878	Elder	Horizontal, compound	Low, cylindrical	60	..	2,300	..	107	3	(1 No. 46 (2 " 64
"Cleopatra"	1878	Humphrys	" "	" "	60	..	2,611	..	107.9	4	(2 No. 36 (2 " 64
"Agamemnon"	1880	Penn	Vertical, composite	High, cylindrical	60	..	6,000	..	86	6	54
"Polyphemus"	1882	Humphrys	Horizontal, compound	Locomotive cylindric'l	120	..	5,500	..	120	4	(2 No. 38 (2 " 64
"Satellite" (without blast)	1882	"	" "	Low, cylindrical	90	..	1,115	..	98.5	2	(1 No. 36 (1 " 62
"Banterer"	1880	Barrow Co.	" "	" "	60	..	452	..	126	2	(1 No. 28 (1 " 48
First-class torpedo-boat	1880	Thornycroft	Vertical, compound	Locomotive, cylindric'l	120	..	460	..	438	2	(1 No. 12¾ (1 " 30¾

In preparing this table I have to acknowledge my indebtedness to Messrs. Joshua Field and John Penn, who have kindly supplied me with p
Engineer-in-Chief of the Navy, for much information respecting the later vessels

evo-lons er ute	Cylinders.				Pistons.		Weight.				Weight per I. H. P.				I. H. P. per		
	No.	Diameter.	Stroke.	Cubic capacity.	Speed per min.	V'lume swept out per min'te.	Engines	Propellers and shafting.	Boilers and water.	Total.	Engines	Propellers and shafting.	Boilers and water.	Total.	Cubic foot of cylinder	Cubic foot swept out by piston.	Ton of weight.
		ins.	ft. in.	cub. ft.	feet.	cub. ft.	tons.	tons.	tons.	tons.	lbs.	lbs.	lbs.	lbs.			
.5	2	55⅛	5 0	168	175	5,880	..	..	..	275	..	..	..	1,550	2.38	0.068	1.45
	4	72	8 0	904	218	23,504	..	..	..	700	..	..	..	980	1.77	0.068	2.3
.5	2	79⅛	5 9	393	178	12,174	165	48	144	357	361	105	315	781	2.6	0.084	2.87
	4	72	8 0	904	240	27,108	230	117	260	607	272	136	306	714	2.1	0.07	3.14
	2	82	6 0	440	192	14,083	117	43	135	295	222	82	256	560	2.68	0.08	4.0
.5	2	64	6 0	268	246	11,008	67	31	145	243	180	93	386	653	3.104	0.076	3.43
.5	2	72	7 0	396	287	16,230	95	41	139	275	164	70	240	474	3.28	0.08	4.72
	2	=77⅝	3 6	230	302	25,766	121	47	257	425	133	50	282	465	8.89	0.79	4.82
	2	=82	4 0	293	432	31,644	143	60	341	544	106	45	254	405	10.25	0.095	5.52
	2	=82	3 8	268	410	30,023	139	65	350	554	102	48	257	407	11.38	0.101	5.51
	2	76	3 6	220	385	24 200	135	50	244	429	127	47	228	402	10.86	0.098	5.57
	2	82	4 0	293	417	30,571	180	62	300	542	158	54	264	476	8.68	0.083	4.7
.4	2	92	4 0	369	467	43,120	230	76	416	722	117	39	212	368	11.93	0.102	6.1
	2	76	3 6	220	406	25,520	119	47	225	391	118	46	223	387	10.27	0.088	5.78
	2	82	4 4	293	475	34,831	191	48	379	618	128	32	253	413	11.41	0.096	5.42
.75	2	=104¼	4 0	474	438	51,903	240	97	550	887	96	38	221	355	11.75	0.107	6.28
	2	101	4 0	445	426	47,394	291	115	564	970	110	43	213	366	11.1	0.121	6.09
	2	96	4 0	402	464	46,646	215	78	447	740	113	41	236	390	10.55	0.09	5.73
.6	2	=104¼	9 0	514	414	48,954	316	98	629	1,043	108	33	215	356	12.72	0.133	6.27
	2	96	3 4	382	472	48,089	223	85	303	611	123	47	168	338	10.58	0.084	6.6
	2	=118	4 6	684	639	97,128	445	99	547	1,091	117	26	144	287	12.47	0.088	7.8
.5	2	=104¼	4 0	474	596	70,594	347	88	550	985	106	26	167	299	15.53	0.104	7.5
	2	88	3 6	295	518	43,719	173	55	271	499	94	30	147	271	14.0	0.094	8.28
	4	77	3 0	388	451	58,285	229	61	345	635	106	28	160	294	12.46	0.08	7.6
	2	98	4 0	419	547	57,294	266	60	334	660	121	27	152	300	11.7	0.09	7.4
	2	=86⅛	3 9	308	592	47,834	216	49	293	558	107	24	145	276	15.0	0.095	8.1
6	4	72	3 0	339	490	55,394	258	59	354	671	112	25	153	290	15.26	0.09	7.7
9	4	72	3 0	339	443	50,128	306	72	336	714	127	30	140	297	15.8	0.107	7.5
8	4	=80	3 3	455	499	69,801	354	92	456	882	113	31	154	298	14.6	0.09	7.5
5	4	77	3 6	453	542	70,173	370	101	504	975	122	33	180	345	13.9	0.089	6.4
	2	100	4 6	490	665	72,496	336	88	527	951	122	32	192	346	12.55	0.08	6.5
5	2	(1 No. 55½ (1 " 97½	2 9	143	542	28,184	130	27	162	319	126	26	157	309	16.15	0.082	7.24
	6	(2 No. 70 (4 " 90	4 0	707	528	93,324	497	167	656	1,320	131	44	173	348	12.02	0.09	6.4
13	6	(2 No. 66 (4 " 90	4 6	795	604	106,739	528	128	705	1,361	144	35	192	371	10.32	0.077	6.0
	3	(1 No. 73 (2 " 92	4 0	369	608	56,179	301	60	482	843	125	28	200	353	14.7	0.096	6.4
5	6	(2 No. 70 (4 " 90	4 0	707	572	101,100	532	112	752	1,396	140	30	198	368	12.0	0.084	6.07
5	4	(2 No. 44 (2 " 85	4 0	315	524	41,291	242	68	334	644	153	43	211	407	11.2	0.086	5.48
75	4	(2 No. 70 (2 " 114	3 10	537	604	84,577	426	113	664	1,203	124	33	193	350	14.3	0.091	6.4
	3	(1 No. 73 (2 " 93½	4 0	380	568	53,960	353	65	483	901	150	28	206	384	13.8	0.097	5.82
	8	(4 No. 41 (4 " 75	3 0	368	582	71,411	382	65	573	1,020	111	19	166	296	20.96	0.108	7.56
	4	(2 No. 60 (2 " 104	3 6	413	5	66,080	293	107	556	956	105	38	200	343	15.12	0.094	6.5
	6	54	3 3	310	546	52,098	404	82	588	1,074	150	31	219	400	19.38	0.115	5.5
	3	(1 No. 46 (2 " 64	2 9	123	588	26,294	127	31	214	372	124	31	208	363	18.7	0.087	6.2
9	4	(2 No. 36 (2 " 64	2 6	111.5	540	24,062	121	35	201	357	104	30	172	306	23.4	0.109	7.3
	6	54	3 3	310	559	53,329	433	105	598	1,136	161	40	223	424	19.3	0.112	5.28
	4	(2 No. 38 (2 " 64	3 3	145	780	34,866	183	46	209	438	75	18	85	178	38.0	0.158	12.56
5	2	(1 No. 36 (1 " 62	2 6	52	492	10,244	55	15	110	180	110	30	211	351	21.44	0.108	6.19
	2	(1 No. 28 (1 " 48	1 6	19	378	4,788	27	6	41	74	134	30	203	367	23.8	0.094	6.1
	2	(1 No. 19¾ (1 " 30⅞	1 0	2.4	876	2,102	4¼	¾	7¼	12¼	20.7	3.65	35.3	59.65	191.6	0.219	37.66

upplied me with particulars of the machinery fitted in the earlier war-ships by their respective firms and also to Mr. J. Wright, C.B., the later vessels and for permission to make use of certain official records.

"Magicienne," which ship was engined by Messrs. Penn in 1850. The pressure of steam in the boilers was 14 lbs. per square inch, piston speed 287 feet per minute, I.H.P. 1,300, and total weight of machinery 275 tons. In this engine 3.28 I.H.P. were developed per cubic foot of cylinder, and 4.72 I.H.P. per ton of weight.

The introduction of the screw-propeller for the propulsion of ships was the most important step in the progress of steam navigation. In order to obtain the same speed of ship, it was necessary to drive the screw-propeller at a much greater number of revolutions than the paddle-wheel. When the screw was first introduced, it was not considered practicable to drive the pistons at a sufficiently high rate of speed to enable the engine-shaft to be connected directly to the propeller shafting, and the earlier engines used for working screw-propellers were *geared*, so that the screw-shaft was caused to revolve more rapidly than the engine-shaft. A large spur-wheel keyed on the end of the crank-shaft of the engine worked into a pinion on the screw-propeller shafting, so that the speed of the engine-shaft might be multiplied on the screw-shaft as many times as might be required. The pressures of steam and speeds of piston employed with these *geared engines* were practically the same as those of the paddle-wheel engines that immediately preceded them, so that while it is interesting to note this step it is not necessary to discuss it further.

Soon after the introduction of the screw-propeller, improvements in workmanship, appliances, and mechanical details so far advanced, that the speeds, both of piston and of revolution, could be sufficiently increased to enable the crank-shaft to be coupled directly to the screw shafting. The boilers for these screw engines were made sufficiently strong to carry higher steam pressures, and the increase both of the pressure of steam used, and of the speed at which the pistons were worked, led to a very considerable increase in the power that could be obtained within a given weight and space, and gave a great impetus to the advance of marine engineering. It is quite certain that the very powerful engines which are now so general would have been altogether impossible, had not the screw-propeller superseded the paddle-wheel. During the period 1850-60, a number of wooden frigates and corvettes, fitted with horizontal screw engines, were added to the Navy. The engines were placed horizontally, in order to keep them below the level of the water-line, so as to be protected from the effect of shot and shell. The pressure of steam used was about 20 lbs. per square inch, and, in the majority of the better examples, the speed of piston was increased to about 400 feet per minute. In a few cases, the speeds of piston were still higher than this; the "Doris," for example, of 3,000 I.H.P., having a piston speed of 432 feet per minute, and the "Victoria," of 4,400 I.H.P., a piston speed of 467 feet, per minute. The engines were all jet condensing, and very little expansion was carried out in the cylinders, so that the consumption of coal for the power obtained was high: this, however, only indirectly affects the point under consideration at present. As the average results of this type, we may take—

I.H.P. developed per cubic foot of cylinder..... =10.0
I.H.P. developed per ton of weight.... = 5.5

This will be seen to be a very considerable advance from the best examples of the slower moving paddle-wheel engines.

The engines fitted in the earlier ironclads were very similar in design to those just mentioned; but as they were of larger power, and the beam of the ship permitted a considerable increase in the length of stroke, the speeds of piston were somewhat higher, and the average results were rather better than those quoted above; as may be seen by reference to the table appended to this paper.

With the jet injection condensers fitted in the earlier ships, in which the steam was condensed by actual mixing with sea-water, the feed-water was practically as salt as the sea-water itself, and a pressure of from 20 to 25 lbs. per square inch was considered to be the highest that could be safely carried in marine boilers, in consequence of the danger that would result from scale accumulating on the heating surfaces. The general adoption of surface condensation, however, overcame this difficulty, by enabling the boilers to be fed with fresh water. In these condensers the steam is condensed by being brought in contact

with the cold surfaces of a series of small tubes, through, or around which, cold sea-water is kept circulating, by the agency of a pump. There is, therefore, no admixture with the sea-water, and the fear of overheating from incrustation on the heating surfaces of the boilers is thereby removed. Since the year 1860, this system has become universal for marine purposes, and has rendered high pressures for steam navigation practicable.

When the above system was first introduced, the old flat-sided boilers, made to fit the section of the ship, were still retained. The form of shell in these boilers is obviously unfit for high pressures, but they were strengthened by fitting additional stays, &c., to enable them to carry working steam pressures of 30 to 35 lbs. per square inch, and the great majority of the war-vessels built during the years 1860-70 were fitted with surface-condensing engines, worked with steam of this pressure. The piston speeds were also considerably increased, especially in the larger ships, in which a long stroke could be obtained. In fact, during this decade, and with this type of machinery, the speed of piston of marine engines reached a point which has only been exceeded in a few ships of recent construction. With this type of engine, the piston speeds varied from 500 to as high as 665 feet per minute. To promote economy of fuel, the cylinders were generally made very large to allow for a considerable amount of expansion at full power, and the boilers were fitted with superheaters, so that the reduction of weight was not so great as might have been anticipated from the augmentation of the piston speed. In the majority of these engines, between 13 and 14 I.H.P. were developed per cubic foot of cylinder, and about $7\frac{1}{2}$ I.H.P. per ton of weight. In some engines of this class fitted to several of the twin-screw iron-clads, the speed of piston barely reached 500 feet per minute, but the other results were as given above.

We now come to the ordinary type of compound engine which has been fitted to nearly all war-ships since 1870, and which may be considered as the general type of marine steam engine of the present day. In these engines the steam from the boilers is only admitted direct to a small cylinder, usually known as the high-pressure cylinder, and at the end of the stroke in that cylinder, instead of passing at once to the condenser, the steam enters one or more additional and larger cylinders, in which the expansion is completed; after which the steam passes to the condenser. The boilers are therefore only in direct communication with the high-pressure cylinders, and the condensers with the low-pressure cylinders.

The working steam pressure in the Royal Navy with this type of engine hitherto has been from 60 to 70 lbs. per square inch. The engines now under construction are designed to be worked with steam of 90 lbs. pressure. As pointed out in the earlier part of this paper the principal object aimed at in increasing the pressure of steam has been to increase the economy of working, and the change from the ordinary surface-condensing engine, with 30 lbs. steam pressure, to the compound engine with 60 lbs. pressure, resulted in a reduction of the coal consumption per I.H.P., of between 30 and 40 per cent.

This step, however, has not been accompanied by a corresponding increase in piston speed, and decrease in dimensions and weight required per I.H.P. In fact, it must be admitted that, although the present type of compound engine is lighter than simple expansion engines worked at the same steam pressure, and with an equal amount of expansion, would be, yet the machinery as a whole is generally heavier than that of the surface-condensing engines with flat-sided boilers, worked with steam of 30 lbs. pressure which immediately preceded them, and the piston speeds are certainly no higher.

The only advantage, therefore, in point of reduction of weight and space that has been gained, as yet, by the introduction of compound engines and high-pressure boilers has been the reduction of coal-bunker space required. This is most important, but it scarcely comes within the range of the present paper, though intimately connected with it.

I will endeavor to point out the causes of this apparent check in the reduction of weight, &c., and to indicate what appears to be the most probable direction in which advance in the future is likely to take place. As a matter of course in

such a case it is impossible to speak with any degree of confidence; all that can be done is to discuss the several points that push themselves forward and suggest the most reasonable and probable solution, so far as our present knowledge, experience, and judgment will guide us.

The first point that strikes us is the increased weight of the boilers. For example, compare the boilers of the "Devastation" with those of the "Nelson." The engines of both ships developed rather more than 6,000 I.H.P. The boilers of the "Devastation" are flat-sided, pressed to 30 lbs. per square inch, and, including water, weigh only 456 tons. The boilers of the "Nelson" are cylindrical, pressed to 60 lbs., and weigh 556 tons, including water. In other words, while the "Devastation's" boilers weigh 154 lbs. per I.H.P., the boilers of the "Nelson" weigh 200 lbs. per I.H.P., or 30 per cent. more. Again, compare the "Inflexible" with the "Hercules," both of which ships have engines of about the same power. The boilers of the "Hercules," loaded to 30 lbs. pressure, weigh 547 tons, or 144 lbs. per I.H.P., whilst the cylindrical boilers of the "Inflexible" weigh 752 tons, or 198 lbs. per I.H.P., which is an increase of 37½ per cent.

This increase of weight may be to some extent attributed to the increased strength necessary to carry the higher steam pressure. This, however, is insufficient to account for all the increase, for, in consequence of the more economical working of the engines, less steam is required to be generated, so that the volumes of the boilers and the areas of heating and grate surface may be made less than in the low-pressure boilers.

The principal cause of the increased weight of the boilers appears to be due to the additional thickness of plate allowed to provide against the effects of corrosion. Many of the earlier boilers, fed with water from surface condensers, were so rapidly weakened by corrosion that they had to be renewed after having been at work for one commission only. The expense of opening out the ship to do this was so great that it was considered desirable to increase the thickness of the shell plates, to enable the boilers to be kept in the ship, without the necessity of removal, for at least two commissions.

By the introduction of steel plates and more improved systems of management, it is hoped that this difficulty will be to a great extent removed. Steel plates are more uniform in structure and much stronger than iron, so that the scantlings may be reduced for a given strength; and now that the mystery that appeared for some time to enshroud the subject of the corrosion of marine boilers has been dispelled, and the true causes of the action ascertained, it appears probable that a reduction in the *factor of safety* usually employed may be safely made. The great importance of this would result from the increase in the maximum working pressure of steam that could then be carried with the present type of marine boiler.

To illustrate this point, let us consider the case of a cylindrical boiler 10 feet in diameter, the shell of which is made of steel plates ¾ of an inch thick. The tensile strength of these plates is usually specified to be not less than 26, nor more than 30, tons per square inch. Many engineers are desirous of raising the lower limit of strength, and this may be possible before long; but for our present purpose we will take the lower limit of 26 tons, and estimate the difference in the pressures of steam that could be carried by allowing factors of safety of 8 and of 5 respectively. The strength of the joint has been taken as 0.75 of that of the solid plate.

If 8 be taken as the factor of safety, the maximum working stress allowed on the material would be one-eighth of the ultimate stress, or 7,280 lbs. per square inch. This would be produced by a working steam pressure of 68 lbs. per square inch. If, however, a factor of safety of 5 were considered to leave a sufficient margin of strength to provide for all contingencies, the maximum working stress on the material would be increased to 11,648 lbs. per square inch, which would permit a working steam-pressure of 109 lbs. per square inch to be carried. Further, if we suppose that after four or five years' work the plates were uniformly thinned by corrosion to the extent of ⅛ of an inch, the factor of safety in the second case, if the original working pressure were retained, would still be 4.167, which is by many engineers considered ample; but if it were deemed

desirable to retain the original margin of safety, this could be done by reducing the working pressure to 91 lbs. per square inch.

In estimating the strength of a structure like that of the shell of a boiler there are few disturbing elements, and almost exact calculation can be applied. The strength of the material used may be considered uniform, and with proper supervision during manufacture, inferior workmanship may be prevented. The most uncertain element, hitherto, has been the effect of corrosion and wear and tear, and this has caused a high factor of safety to be generally employed. Now, however, that most of the difficulties attending the boiler-corrosion question have been overcome and the methods of reducing or preventing this action have been satisfactorily ascertained, we may hope that marine boilers may retain their original strength for much longer periods than was formerly the case, and it would therefore appear that the factor of safety used for the shells of the boilers may be reduced with advantage.

The criterion of the relative strengths of the several parts is the strength they respectively possess when the boiler is worn out and unfit for further work. It is the usual practice in the Government Dockyards to burst by water pressure, for the sake of experiment, one boiler out of each set condemned, and a mass of very valuable information as to the ultimate condition of the boilers is thereby obtained. I have had, in the course of my duty, to conduct many of these bursting experiments, and, so far as my experience goes, the weakest part has, in every case, proved to be the furnace or combustion chamber, and I think it is quite safe to say that while the present form and dimensions of furnaces and combustion chambers are retained—and there appears to be no tendency to increase the thickness of the plates in these parts—there is no necessity to use a higher factor of safety for the shells than 5. Even with this factor I believe that, when the boilers come to be worn out, the furnaces and combustion chambers will be found to be the weakest parts, notwithstanding the fact that they apparently had a much greater margin of strength than the shells, when new. It must not be forgotten, that in these parts the material is weakened to some *unknown* extent by the working and flanging at the fires during manufacture, and when the boilers are under steam, unequal and unknown strains are brought on the material by the expansion resulting from the heat of the furnaces. It is also probable that the material deteriorates from the alternate heating and cooling to which it is exposed; and corrosive action, if it occurred at all, would probably produce more effect on the heating surfaces than on the shells, which are kept at a much lower and more uniform temperature. The plates in these parts also are generally thinner than in the shells, so that the percentage of loss of strength for a given amount of corrosion would be the greater.

The present type of marine boiler is also a slow and wasteful generator of steam. Even when the draught is forced by means of the steam blast, not more than about 30 lbs. of coal can be burnt per square foot of fire-grate per hour; and only about one-half of this is utilized in evaporating the water. In many cases more than one-half of the heat that the coal is capable of evolving by complete combustion is wasted in various ways. Cylindrical boilers are even more slow and wasteful generators than the old flat-sided boilers.

In order to reduce the weight of the boiler, rapid combustion is necessary. The greater the quantity of coal that can be efficiently burned per square foot of fire-grate per hour, the smaller may the furnaces be made for a given power. In locomotive practice the rate of combustion of coal in ordinary work often reaches as high as from 80 to 100 lbs. per square foot of grate per hour, and in some cases it even exceeds this. This, combined with the smaller amount of water carried, has caused many marine engineers to look to this type as a means of reduction of weight. Mr. Thornycroft, in his fast torpedo-boats, was, I believe, the pioneer in this direction; and he forced the draught by closing the stoke-holds and putting them under air-pressure. The air was blown into the stoke-holds by means of a rotatory fan, and a pressure of air, equal to the weight of from 3 to 6 six inches of water, is easily maintained. In some experiments, made at Portsmouth, to ascertain the perform-

ance of the boiler of a first-class torpedo-boat, it was found that with an air pressure equal to 3 inches of water, 62 lbs. of coal could be burnt per square foot of grate per hour; and when the pressure was raised to 6 inches of water, the rate of combustion was increased to 96 lbs. per square foot of grate per hour.

The only ship of large size in which this plan has been adopted is the torpedo ram "Polyphemus." The machinery of this ship has been constructed by Messrs. Humphrys and Tennant, and every effort has been made to secure lightness. The engines are driven at a high speed, both of piston and of revolution. They are expected when working at full power to make about 120 revolutions per minute and to have a piston speed of about 780 feet per minute. This will give about 38 I.H.P. per cubic foot of cylinder, and 12½ I.H.P. per ton of weight; which is a very great advance on anything yet attained with the ordinary marine engine; and the experiment is most interesting and instructive from both a scientific and practical point of view.

I do not, however, think the locomotive type of boiler will prove itself suitable for marine purposes generally; though it may be useful in some special cases. The water spaces are too confined for general work at sea, and it would, I think, be found impossible to keep the flat sides of the fire-boxes from bulging and becoming unsafe. The great difficulty that has hitherto been experienced with these boilers, even on the trial trips, which have as yet been the only hard work to which they have been subjected in the Service is the leakage of the tubes at ths fire-box ends. This is equally true both of the torpedo-boats and of the "Polyphemus." The cause of this appears to be that the intense heat of the fire being so close to the tube-plate, causes it to expand and compress the ends of the tubes; so that when the fires are checked, the contraction of the tube-plate leaves the tubes slack in their holes. The leakage has shown itself in nearly every case, when the engines were eased after the full-power run, the forced draught being stopped, which reduced the temperature of the fire. The cold air, also, that enters the fire-door when it is opened, impinges directly on the hot tube-plate, without having to pass over such a length of fire as an ordinary marine boiler.

For the present working pressures of steam the ordinary type of marine boiler appears to be the most suitable; and probably little variation in its form need be made, so far as strength is concerned, for pressures up to about 150 lbs. per square inch. I doubt, however, if it would be wise to much exceed that pressure with the existing type of boiler. If pressures beyond this limit be arrived at, it will be, in my opinion, necessary to adopt some form of boiler built entirely of small tubes, to enable the steam to be generated with confidence and safety. I do not profess to indicate what type of *tubulous* boiler will prove most efficient. Those that have been tried hitherto have not given general satisfaction, but it is probable that the failures have been due more to defects in the details of construction or of management, than to causes inherent to, or inseparable from, the type of boiler. The Herreshoff coil-boiler has proved itself economical and efficient for small boats, and is the lightest type yet constructed for a given power. It is absolutely safe, but whether it is adaptable to larger powers has yet to be proved.

With the present type of marine boiler it is necessary that *artificial draught*, of some kind, should be employed for full-power working, in order to keep the dimensions within moderate limits. Until recently the steam blast was the only means used for forcing the fires. This, however, is a very wasteful way of getting steam, especially with surface-condensing engines. Other methods of forcing the draught are—

1. Fitting an exhausting fan in the funnel.
2. Blowing air into closed ashpits.
3. Blowing jets of air into the base of the funnel.
4. Blowing air into closed stokeholds.

The first plan is obviously unsuitable for ships, for the fan would require to be so large to allow all the products of combustion to pass through it, at a sufficiently high velocity, that the apparatus would be too cumbrous and unwieldy.

The blowing of air into closed ashpits is a very efficient plan, but has the objection that the pressure in the furnaces is greater than that in the stokeholds, so

that, unless care be taken when opening the fire doors, accidents are liable to occur. With artificial stoking this plan would probably be found to be both economical and efficient.

The blowing of jets of air into the base of the funnel has been tested by experiment in the French Service, and favorably reported on. It is also on trial in one or two ships belonging to the French Navy; but little is known, as yet, of its practical working and efficiency.

The fourth plan, viz., blowing air into closed stokeholds, which has been adopted from the torpedo-boats, has found most favor in the Royal Navy. The stokeholds of several of the more recent ships are being arranged and fitted, so that, when working at full power, they may be closed in and kept under air pressure by means of fans.

The "Satellite," now completing at Sheerness, is the first ship in which this system has been practically tested. This ship has two independent stokeholds, in each of which there are two boilers. During a three hours' trial made on the 11th instant, with the forward stokehold closed, and kept under an air pressure equal to about one inch of water, the rate of combustion of coal per square foot of grate was raised to 39.4 lbs. per hour, and the I.H.P. developed from the two boilers was 865, or 15.7 I.H.P. per square foot of fire-grate. The average number of revolutions made by the engines per minute was 95.38. On a previous trial made on 3d April, 1882, without artificial draught, the coal burnt per square foot of grate was 18.6 lbs. per hour, and the average I.H.P. developed with four boilers was 1,115. The effect of forcing the draught, in this case, enabled the power obtained from a given set of boilers to be increased from 558 to 865, or about 55 per cent.*

With respect to the engine itself, it is probable that a considerable reduction of weight could be made by the more extended application of steel in construction. Forged steel has for some time been largely used for crank and propeller shafting, piston and connecting rods, &c., and the weights of the shafts have been further reduced by making them hollow. Recently, steel castings have been used, in lieu of cast-iron, for several parts of the machinery. The pistons for the engines of the steel cruisers now under construction at Messrs. R. & J. Napier's, Glasgow, are made of cast steel, and their weight is only about one-half the weight necessary for cast-iron pistons of the same diameter. Mild steel castings of great strength and toughness, and free from blowholes, can now be made, and as the processes of manufacture are more fully developed, I think we may look forward to a considerable extension in the application of this material, which will much facilitate the reduction of weight of marine engines. The general use of *wrought* iron or steel framing for marine engines would be very costly, as it would involve a great expenditure for labor, and this system is only likely to be adopted in special cases. If, however, mild steel castings could be made, at moderate price, to supersede iron castings for the various parts, the extra expense due to increased workmanship would be avoided; and it is most probable that the material would be extensively used.

The engines of the "Nelson," designed by Mr. A. C. Kirk, now the head of the firm of Messrs. R. & J. Napier, of Glasgow, form one of the most complete examples of light wrought iron and steel framing properly and scientifically trussed and secured to the structure of the ship itself that has, as yet, been constructed.* The reduction in weight in this case is considerable, the engines only weighing 105 lbs. per I.H.P., while the average weight for engines of the same class, with ordinary cast-iron framing, is 140 lbs. per I.H.P., or 33 per cent. greater. Engines constructed in this manner are, however, necessarily very expensive in manufacture, as much additional labor is involved, and both the workmanship and material employed must be of the highest quality.

* The steam trials of the "Heroine," sister ship to the "Satellite," took place at Devonport on the 30th and 31st May, 1882. On the 30th May, a six hours' run was made with natural draught only, the average power developed with four boilers being 1,127 I.H.P. On the following day a three hours' trial was made with the two forward boilers, the fires being forced by the steam blast. There were four blast nozzles used in the funnel, each $\frac{7}{8}$ inch diameter, and the average power developed with the two boilers was 695 I.H.P. By the use of the steam jet, therefore, the power of the boilers was increased from 563 to 695, or about 23½ per cent.

* See Journal, vol. xxiii, No. CI, page 614, *et seq.*

It is probable that a saving in weight might be effected if the framing of the engine and of the ship at the section in which the machinery is placed were considered, so far as possible, as one. As a rule the ship is only regarded as a platform to carry the machinery, and the necessary transverse strength is obtained by increasing the weight of the hull, without reference to any strength that might be obtained from the engines. In an able paper by Messrs. Read & Jenkins, of "Llyod's Register," "On the Transverse Strains of Iron Merchant Ships," read at the recent meetings of the Institution of Naval Architects, the necessity of providing additional transverse strengthening in the engine and boiler space in steam-vessels is clearly pointed out. It would, therefore, be an advantage in the design of the engines, particularly when they are required for warships, in which reduction of weight is so important, if the framing could be so arranged and constructed that it would add the necessary additional transverse strength to the section of the ship, instead of being merely a dead weight to be carried by the ship.

This point was emphasized by Mr. F. C. Marshall, of Newcastle, in his paper "On the Marine Engine," read at the meetings of the Institution of Mechanical Engineers, in August, 1881. He says: "Great saving in weight can be effected by careful design, and by judicious selection and adaptation of materials; also by the substitution of trussed framing and a proper mode of securing the engine to the structure of the vessel, in place of the massive cast-iron bedplates and columns of the ordinary engines of commerce." Also: "The hull and engine should be as much as possible one structure; rigidity in one place and elasticity in others is the cause of most of the accidents so costly to the shipowner. Under such conditions mass and solidity cease to be virtues, and the sooner their place is taken by careful design, and the use of the smallest weight of material (of the very best kind for the purpose) consistent with thorough efficiency, the better for all concerned."

The reduction in the weight of the engine that could be effected by improved design and workmanship, and the use of stronger material, although most important, does not, of itself, offer so large a scope for improvement as increase of speed, both of piston and of revolution. These have been highly developed by Mr. Thornycroft in the engines of the fast torpedo-boats, which at full power make about 440 revolutions per minute and have a piston speed of 880 feet per minute. The total weight of the machinery, including boilers and water, is below 60 lbs. per I.H.P. In the "Inflexible" the number of revolutions per minute was 71.5, speed of piston 572 feet per minute, and the total weight of the machinery 358 lbs. per I.H.P. Even in the "Polyphemus," in which the nearest approach to the torpedo type of machinery has been attempted, the estimated number of revolutions per minute is 120, speed of piston 780 feet per minute, and total weight of machinery 178 lbs. per I.H.P.

In pursuing this part of the subject we are met with many difficulties, arising, more especially, from the action of the propeller. The generally accepted theory of propulsion is, that the propeller produces a sternward momentum in the water on which it acts, which momentum measures the thrust exerted on the ship. The larger the quantity of water acted on, therefore, the greater will be the thrust. The usual practice has consequently been to make the diameter of the propeller as large as possible. The surface and edgewise friction of these large propellers is very great, and the large mass of water acted on in each revolution entirely precludes the engines being worked at a high speed of revolution, while they are connected direct to the present type of propeller.

From experiments made by the late Mr. Froude, it would appear that considerably more than one-half of the total energy transmitted to the propeller is wasted from various causes. It is, therefore, probable that the design of improved propelling arrangements affords a large field for invention, from which increased economy of propulsion may be reasonably anticipated in future. A large proportion of the loss of efficiency in existing screws arises from the augmented resistance of the ship from the reduction of the pressure of water under the stern produced by the propeller, so that it is very probable that improved propulsion

may result, as much from some alteration in the form of ship or in the position of propeller, as from modification of the form and arrangement of the propeller and fittings.

The substitution of steel blades in lieu of gun-metal or cast-iron, by offering less resistance, will enable the engines to be driven somewhat faster; but a more radical change than this needed to effect any very substantial reduction in weight and space occupied. It is probable that propellers of smaller diameters, driven at higher speeds, may be used with advantage in many cases. This was clearly shown in the "Iris," in which ship, by reducing the diameter of the screws from 18′ 6½″ to 16′ 3½″, the speed of the ship was increased from 16.577 knots to 18.573 knots; the I.H.P. developed by the engines being practically the same in the two trials. It would appear to be very desirable to make further experiments in this direction, especially with twin-screws, to ascertain how far reduction of diameter and increase of speed of revolution may be efficiently carried.

Mr. Thornycroft, in 1879, patented a new form of propeller, by means of which the propelling effect of a screw of given diameter is much increased. The boss is made small at the forward and large at the after end; and behind the propeller is arranged a body of peculiar form furnished with guide plates or blades, for directing the water projected by the propeller. Around the propeller and body a tube case or hollow guide is fitted, which facilitates the flow of water to the propeller, and regulates its discharge sternwards, after having been operated on by the propeller.

Mr. Thornycroft, in his reply on the discussion which followed his paper on torpedo-boats, read at the Institution of Civil Engineers, in May, 1881, stated that with his propeller, the diameter of the guide tube being 3 feet, 400 I.H.P. was utilized to the best advantage at a speed of 18 knots. Gunboats whose engines develop about 400 I.H.P. have screws generally about 9 feet in diameter. Mr. Thornycroft also calculated that two propellers, on his principle, similar to the model for the "Iris," each 7 feet in diameter, would be sufficient to use 45,000 I.H.P. at 40 knots. Of course, in these cases, the high speed of the ships would allow a full supply of water to the screws, and the statement is not altogether applicable to ships of ordinary form and speed; but it does appear to be probable that by some alteration in the form of ship or propeller, or of both, we may hope to obtain a much greater efficiency of propulsion from propellers of small diameter driven at high speeds. It is in this direction, I think, that a great scope for improvement exists. This, however, cannot be determined theoretically, and little can be done, until by a careful and extended series of experiments more definite knowledge is obtained of the whole of the conditions of the action and efficiency of propellers. It is very probable that we all have very much to learn, and possibly to unlearn, on this subject.

For the present we shall have to continue to use, with probably slight modifications in size and form, the existing screw-propeller, driven at a comparatively slow speed. It is therefore, I think, worthy of consideration whether or not it would be wise to proceed in the direction of making any material increase in the speed of engines, to reduce their dimensions and weight, until a form of propeller adapted for high speeds of revolution has been devised. If high speed engines were used for driving the existing propellers, it would be necessary to interpose gearing to reduce the rate of revolution. This is much objected to by many engineers, but it is possible that the advantages that would be gained thereby would outweigh its disadvantages.

It is only the reversal of the process that took place when the screw-propeller was first introduced. At that time there were no engines suitable to drive it direct, and the old type had to be utilized to drive it by means of multiple gearing. This, however, gave the screw the chance of proving its efficiency, and mechanical science soon produced engines capable of driving it direct. Improvements in the screw-propeller at present appear to have almost arrived at a standstill, so far as speed is concerned, but if gearing be admitted, the weight and space required for the engines could be materially decreased. In this case the gearing would be used to reduce the speed, and might be expected to work much more smoothly

than when the reverse operation had to be performed. If the plan proved successful, we should have the satisfaction of knowing that if a high speed propeller were devised, the engines would be prepared and ready to drive it direct.

The engines of a first-class torpedo-boat, which weigh only 4¼ tons, develop 460 I.H.P., with a speed of 438 revolutions per minute. This is about the same power that is developed by the engines of the gunboats in Her Majesty's Service. The engines of these boats, however, neglecting the boilers and propellers, weigh 27 tons, or more than six times the weight of the engines of the torpedo-boat which develop the same power. In the torpedo-boats the cylinders are 12¾ inches and 20⅞ inches diameter, with a 12-inch stroke; the corresponding dimensions for the gunboat engines are—cylinders, 28 inches and 48 inches diameter, and stroke 18 inches. The speed of piston in the former case is 876 feet per minute, while in the latter it is only 378 feet. It is therefore clear, that if the gunboat engines could, with safety, be replaced by those of the torpedo-boat type, and the propeller shafting driven by means of gearing, a considerable saving of weight and space might be effected.

How far this system would be generally applicable it is difficult, if not impossible, to predict. One thing is certain, viz., that in order to enable the weights to be much further reduced, the speed must be increased. The only way of obtaining this increase of speed of the engines, with ths existing form and dimensions of propeller, is to drive the propeller shafting by means of gearing, so as to reduce the speed of revolution. Whether, or not, this is desirable, and likely to increase efficiency, can only be determined by experience. The point is, in my opinion, worthy of consideration, so that its relative advantages and disadvantages may be fully discussed and thoroughly threshed out.

In order to drive engines at high speeds of revolution it is desirable that the resultant driving forces on the crank should be made to be as nearly as possible uniform. To effect this, the *weights of the reciprocating parts* of the engines should be carefully adjusted to suit the required maximum speed, so as to cause the resulting tangential pressures on the crank-pin to vary as little as possible. It is very important that this should be carefully attended to in all high speed engines. The ordinates of the indicator diagram only give the pressures on the piston; and to obtain the corresponding pressures on the crank-pin, it is necessary to combine, with the indicator diagram, a diagram showing the work expended on the acceleration and given out during the retardation of the motion of the reciprocating parts of the engines. It is therefore clear that *strength* is not the only point that should be considered in the design of these parts; but that, if possible, their *weight* also should be so arranged that, when the engines are working at full speed, the effect of the inertia of the reciprocating parts may tend to produce uniformity in the tangential forces acting on the crank-pin. I am unable to do more than simply mention this point; which, however, is one that may make all the difference between a smoothly and quietly working engine and one whose motion is irregular.

One other point requires to be mentioned with reference to the probable increase in the working pressures of steam, which, although it primarily affects the economy of steam, is also important as regards the strains on the framing and shafting, &c. The ordinary two-cylinder compound engine, with initial steam pressure of 80 to 90 lbs. per square inch, has now practically arrived at the same position, with respect to range of expansion and temperature in each cylinder, that the simple expansion engine, with steam of 30 to 40 lbs. pressure, was in, when it was superseded by the compound engine. If, therefore, the pressures are increased beyond this limit, it will be necessary to divide the expansion of the steam into three stages in order to increase its practical efficiency, and to reduce the maximum strains on the shafting, framing, &c. This has been carried out in a few ships, one of the most recent being the steamship "Aberdeen," built by Messrs. R. & J. Napier, of Glasgow, and fitted with triple expansion engines, designed to be worked with steam at a pressure of 125 lbs. per square inch.

I cannot hope that I have done more, in this paper, than to have merely given a rapid and imperfect review of the

changes that have taken place during the past 50 years in the relations between the size, speed, and power of marine engines, and to have indicated, so far as our present knowledge and experience serve as guides, what appears to be the most probable direction for future advance.

I think it will be admitted that the progress already made is great. To say nothing of the more special types of marine engines, which may perhaps be considered to some extent as experimental, we may just compare the "Rhadamanthus," mentioned in the earlier part of this paper, the engines of which ship were built in 1832, with the "Cleopatra," built in 1878. The machinery of the "Rhadamanthus" weighed 275 tons and developed 400 I.H.P. The machinery of the "Cleopatra," which weighs 357 tons, developed at full power 2,611 I.H.P. Machinery of the "Cleopatra" type, of the same weight as that of the "Rhadamanthus," would be capable of developing 2,011 I.H.P., or five times the power of the "Rhadamanthus." It would appear from the recent trials of the "Satellite" that, with closed stokeholds under very moderate air pressure, machinery of modern design and construction would develop at least six times as much power as the earlier types of engines of equal weight.

One other feature is the great increase in the total engine power that can now be made available for the propulsion of ships. For example, take the case of the "Terrible," which represented the finest type of steam war-ship of her day. Her maximum I.H.P. was less than 2,000, and her speed about 10 knots. In the despatch vessel "Iris," two sets of engines are fitted, capable of developing 7,700 I.H.P., and of driving the ship at a speed of 18½ knots per hour. In several ships recently built, engines capable of developing 10,000 I.H.P. have been fitted.

So far as we are able to judge, the "Terrible" was as near finality in 1845 as the "Iris" and "Inflexible" are to-day. I think, therefore, we need not despair of the future, but may confidently look forward to still further progress in marine engineering. In what direction advance will be made it is, perhaps, unsafe to predict, but it does appear probable that the fields which afford the most enlarged scope for radical changes are the boilers and the propellers.

THE INSPECTION OF PUBLIC WORKS.

By PROF. GEORGE L. VOSE.

Proceedings of the Society of Arts.

NEARLY all the disasters which occur from the breaking down of bridges are caused by defects which would be easily detected by an efficient system of inspection. Not less than forty bridges fall every year in the United States. No system of public inspection or control at present existing has been able to detect, in advance, the defects in these structures, nor to prevent the disasters. After a defective bridge falls, it is in nearly every case easy to see why it did so. It would be just about as easy, in most cases, to tell in advance that such a structure would fall if it happened to be heavily loaded. Hundreds of bridges are to-day standing in this country simply because they never happened to have received the load which is any time liable to come upon them

In a country where government controls all matters on which the public safety depends, and where no bridge over which the public is to pass is allowed to be built except after the plans have been approved by competent authority, where no work can be executed except under the rigid inspection of the best experts, nor opened to the public until it has been officially tested and accepted, it makes little or no difference whether the public is informed or not upon these matters; but in a country like the United States, where any man may at any time open a shop for the manufacture of bridges, whether he knows anything about the matter or not, and is at liberty to use cheap and insufficient materials, and where public officers are always to be found ready to buy such bridges, simply

because the first cost is low, and to place them in the public ways, it makes a good deal of difference.

To see what may be accomplished by an efficient system of public inspection, it is necessary to know something in regard to the structures to be inspected. We have now in common use in this country, both upon our roads and our railroads, bridges made entirely of iron, bridges of wood and iron combined, and occasionally, though not often nowadays, a bridge entirely of wood, and these structures are to be seen of a great variety of patterns, of all sizes, and in every stage of preservation. Of late so great has been the demand for bridge-work that this branch of engineering has become a trade by itself, and we find immense works, fitted up with an endless variety of the most admirably adapted machine tools devoted exclusively to the making of bridges of wood, iron, steel, or all combined. As in all divisions of labor the result of this specialization has been to improve the product, to lessen the cost, and to increase the demand, until many of our large firms reckon the length of bridging they have erected by miles instead of feet. As usual, however, in such cases, unprincipled adventurers are not wanting who, taking advantage of a great demand, do not hesitate to fit up cheap shops, to buy poor materials, and to flood the market with a class of bridges made with a single object in view, viz., to sell, relying for custom upon the ignorance, or something worse, of public officials. Not a year passes in which some of these wretched traps do not tumble down, and cause a greater or less loss of life, and, at the same time, with uninformed people, throw discredit on the whole modern system of bridge-building.

An impression exists in the minds of many persons that it is purely a matter of opinion whether a bridge is safe or not. In very many cases, however, perhaps in most, it is not at all a matter of opinion, but a matter of fact, and of arithmetic. The whole question always comes to this: Is the material in this bridge of good quality, is there enough of it, is it correctly disposed, and properly put together? With given dimensions, and knowing the load to be carried, it is a matter of the very simplest computation to fix the size of each member. We know what one square inch of iron will hold, and we know also the total number of pounds to be sustained, and it is no matter of opinion, but one of simple division, how many times one will go into the other.

In 1875 the American Society of Civil Engineers, in view of the repeated bridge disasters in this country, appointed a committee to report upon "The Means of Averting Bridge Accidents."

The conclusions arrived at by this committee are of great weight, and their tables of the loads which highway and railroad bridges should be capable of carrying [these were here given and explained by the speaker] are the result of valuable experience.

To pass now to railroad bridges, we find here a very heavy load coming upon the structure in a sudden and often very violent manner. Experiment and observation both indicate that a rapidly moving load produces an effect equal to double the same load at rest. This effect is seen much more upon short bridges, where the moving load is large in proportion to the weight of the bridge, than upon long spans, where the weight of the bridge itself is considerable. The acttal load upon a short bridge is also much more per foot than upon a long one, because the locomotive, which is much heavier than an equal length of cars, may cover the whole of a short span, but only a part of a longer one. [Tables of the load per running foot for railroad bridges were here given and discussed.]

The load which any bridge will be required to carry being determined, and the general plan and dimensions fixed, the several strains on the different members follow by a simple process of arithmetic, leaving to be determined the actual dimensions of the various parts.

It will, of course, be understood when it is said that bridge-building may be called a science that it can only be so when in the hands of an engineer whose judgment has been matured by wide experience, and who understands that no mechanical philosophy can be applied to practice which is not subject to the contingencies of workmanship. There are many bridges which will stand the test of figures very well, which are, nevertheless, very poor structures. The general

plan of a bridge may be good, the computations all right, and yet it may break down under the first train that passes over it. There are many practical considerations that cannot, at any rate have not yet, been reduced to figures. It is not enough that the strain upon each member of a bridge should be correctly estimated, and fall within the safe limits; the different members of the bridge must be so connected, and the mechanical details such as to insure, under all conditions, the assumed action of the several parts. In fine, while we can say that a bridge that does not stand the test of arithmetic is a bad bridge, we cannot always say that a structure which does stand such a test is a good one.

We often hear it argued that a bridge must be safe since it has been submitted to a heavy load and did not break down. Such a test means absolutely nothing. It does not even show that the bridge will bear the same load again, much less does it show that it has the proper margin for safety. It simply shows that it did not break down at that time. Every rotten, worn-out and defective bridge that ever fell has been submitted to exactly that test. More than this, it has repeatedly happened that a heavy train has passed over a bridge in apparent safety, while a much lighter one, passing directly afterwards has gone through. In almost all such cases the structure has been weak and defective, and finally some heavy load passes over and cripples the bridge, so that the next load produces a disaster.

In view of the preceding, what shall we say of a bridge company that deliberately builds a bridge in the middle of a large town, where it will be subjected to heavy teaming, and, owing to its peculiar location, to many crowds, and warrants to the town that it shall safely hold a ton per running foot, when the very simplest computation shows beyond chance of dispute that such a load will strain the iron to 40,000 pounds per square inch. We are to say either that such a company is so ignorant that it does not know the difference between a good bridge and a bad one, or else so wicked as to knowingly subject the public to a wretchedly unsafe bridge. The case referred to is not an imaginary one, but existed recently in the main street of a large New England town. The joints in that bridge which could safely hold but 20,000 pounds were required to hold 60,000 pounds under the load which the builders had warranted the bridge to carry safely. The case was so bad that, after a lengthy controversy, the town officers had a thorough expert examination of the bridge, which promptly condemned it as in imminent danger of falling and as having a factor of safety of only 1.15, which is practically no factor at all. Notwithstanding all this, and in the face of the report, the president of the bridge company came out with a letter in the papers, in which he pronounced the bridge "perfectly safe." Thus we have actually the president of a bridge company in this country stating openly that a factor of safety of 1.15 makes a bridge perfectly safe: or, in other words, that a bridge can safely bear the load that will break it down, for he very wisely made not the slightest attempt to disprove any of the conclusions of the commission. And this company has built hundreds of highway bridges all over the United States, and is building others to-day wherever it can find town or county officers ignorant enough to buy them. It might be supposed that under the above condemnation the authorities controlling the bridge would have taken some steps to prevent the coming disaster. They did, however, nothing of the kind, but allowed the public to travel over it for more than a year, at the most fearful risk, until public indignation became so strong that a special town meeting was called, and a committee appointed to remove the old bridge and build a new one. One of the worst cases of utterly dishonest bridge-building that we have heard, of late years, in Massachusetts, is that of the iron highway bridge across the Merrimac, at Groveland, a few miles below Haverhill, one span of which broke down last January. Can we do anything to prevent towns and counties from being imposed upon by dishonest builders? We certainly can, if those who control these matters care enough about it to do it. By the employment of a competent engineer to make the specifications, of a lawyer to draw up the contracts, and by having all materials and workmanship submitted to the engineer or inspector

before acceptance, an iron or other bridge may be had which will be absolutely safe.

One point always brought forward when an iron bridge breaks down is the supposed deterioration of iron under repeated straining, and we are gravely told that, after a while, all iron loses its fiber and becomes crystalline. This is one of the mysteries which some persons conjure up at tolerably regular intervals to cover their ignorance. It is perfectly well known with engineers, the world over, that with good iron nothing of the kind ever occurs. We have only to allow the proper margin for safety, as our first-class builders all do, and this antiquated objection at once vanishes. The examples of the long duration of iron in large bridges are numerous and conclusive.

The question is frequently asked: Does not extreme cold weaken iron bridges? To this it may be replied that no iron bridge made by a reliable company has ever shown the slightest indications of anything of the kind, though they have been used for many years in Russia, Norway, Sweden, and Canada, and nothing that we know in regard to iron gives us any reason to suppose that anything of the kind will ever happen. But here, again, everything turns upon the quality of the iron. Iron containing phosphorus is "cold short," or brittle when cold, and will break quicker under repeated and sudden shocks in cold weather than when it is warm. An immense number of experiments made upon all sorts of iron shows conclusively that cold has no effect whatever upon the strength of good iron. The securing of such iron is a matter to which the utmost attention is paid by our first-class bridge-building firms.

At least half the most disastrous failures of railroad bridges in the United States have been due to a defective system of flooring. With a very large proportion of our bridges the failure of a rail, the breaking of an axle, or anything which will throw the train from the track is almost sure to be followed by the breaking down of the bridge. The cross-ties are in many cases very short, and the floor is proportioned for a train *on* and not *off* the rails. When an engine on such a floor leaves the track it plunges off the ends of the cross-ties into the open space between the stringers and the chords, and generally wrecks the bridge. To prevent this the cross-ties should be long and well supported, and placed so close that a derailed engine cannot cut through them. The track should also be provided with guard timbers, well fastened, and the width between the trusses should be so great that the wheels of a derailed train will be stopped by the guard rail before the side of the widest car can strike the truss.

The importance of a substantial floor system has been very fully recognized by the Railroad Commissioners of Massachusetts, who have recently issued a very suggestive circular, accompanied by numerous examples of track construction for railway bridges. If this circular receives proper attention it is sure to produce good results.

Another point which has often been neglected is making sufficient provision to resist the force of the wind. A tornado, such as is not uncommon in this country, will exert a force of forty pounds per square foot, which, upon the side of a wooden bridge say of 200 feet span and 25 feet high, and boarded up as many bridges are, would amount to a lateral thrust of no less than 100 tons, and this load would be applied in the worst possible manner, viz., in a series of shocks. There have been many cases in this country where bridges have been blown down, and a case recently occurred where an iron railroad bridge of 180 feet span and 30 feet high, and presenting apparently almost no surface to the wind, was blown so much out of line that the track had to be shifted. The recent terrible disaster at the Frith of Tay was no doubt due to this cause.

Having seen something of the structures which require inspecting, let us now see what kind of inspection we have in this country, and the result of it, and let us also see the inspection which we might have, and the results which might be produced.

Looking first at railroad bridges, it might be supposed that no one could be so much interested in keeping such structures in good order as the companies which own those bridges, and which have the bills to pay in case of disaster. This is of course so, but in

spite of the fact the Ashtabula bridge broke down on one of the best managed lines in the country, and cost the company over half a million dollars in damages.

During the past ten years over two hundred railroad brdges in the United States have broken down. These bridges were all kept under such inspection as the railroad companies owning them considered sufficient, or such as they could afford; but either the supervision was defective, or the companies knowingly continued the use of unsafe bridges, and this fault has by no means been confined to the smaller and poorer roads. It would seem, therefore, that inspection by the companies themselves has not been sufficient. It certainly has not been enough to prevent two hundred disasters in ten years. It is the custom in several of the United States to maintain what is termed a Railroad Commission. Except in Massachusetts, where the State has taken care to secure men of ability for Railroad Commissioners, it is very doubtful whether these commissioners have been of any use. In many States it is very certain that, in regard to matters of inspection, the work of these boards has been simply a farce: and it could hardly be otherwise in a State which pays its commissioners only $1,000 salary, or worse yet, as in some cases, only $500. Add to this that in many cases the appointments have been purely political ones, and we can see the absurdity of expecting any results of value. We should hardly suppose that three men, in many cases entirely unaquainted with mechanical matters, could, by riding over a railroad once or twice a year, occasionally getting out to examine the paint on the outside of the boards which conceal a truss from view, judge very correctly of the elastic limit of the iron rods which they have never seen, and of which they do not even know the existence. For ample proof of the utter inefficiency of the present system we have only to compare the reports of the Railroad Commissioners in almost any State with the actual condition of the structures described.

While in a few States the inspection is nat quite so bad as that referred to, as a general thing it is no better, and we have no right to expect anything better under the present system. The State inspection which we have had throughout this country has not prevented the breaking down of one hundred bridges in the past ten years. Twenty States have railroad commissioners, but in nine of them the commission consists of only a single man, who in some cases is paid five hundred dollars a year. A State can pay five hundred dollars a year for having its bridges inspected, and it can get such service as never did and never will prevent a disaster, or it can pay a good price for competent inspection which will be worth ten times the money to the State. The money which the Lake Shore Railroad paid in damages for the Ashtabula disaster alone would have employed permanently six men at five thousand dollars a year each, and a hundred lives would have been saved besides.

With regard to highway bridges we are, if possible, even worse off than in regard to railway bridges, for in the case of such structures neither the owners nor the State make any pretence at inspection. It is impossible to say how many highway bridges have broken down during the past ten years, but it is estimated by bridge-builders that the number cannot be less than two hundred. This is about one a year for every two States, and is no doubt far within the truth. It is quite as important that highway bridges should be built and kept under some kind of control as that railroad bridges should, perhaps even more so, as towns and counties are much more liable to be imposed upon by dishonest bridge-builders than railroad companies are.

Admitting now that structures so important to the public safety as bridges both upon roads and railroads ought to be kept under rigid inspection and control, and that no system at present existing has been able to prevent the most fearful catastrophes, what shall we do?

Directly after the Ashtabula disaster, the Ohio legislative committee appointed to investigate that affair presented to the Legislature a bill "to secure greater safety for public travel over bridges," in which were plainly specified the loads for which all bridges should be proportioned, the maximum strain to which the iron should be subjected, and a method

for inspecting the plans of all bridges before building, and the bridges themselves during and after construction. The Governor with the consent of the senate, was to appoint the inspector for a term of five years, at a salary not exceeding $3,000 a year. Such inspector to pass a satisfactory examination before a committee of the American Society of Civil Engineers, themselves practised experts in bridge construction, and he was also to take a suitable oath for the faithful performance of his duty. This bill never became a law. An appropriation was made for a short time to pay for certain examinations, and there the matter stopped.

The committee of the American Society of Engineers was not agreed upon this matter. Messrs. James B. Eads and Charles Shaler Smith suggested the appointment in each State of an expert to whom all plans should be submitted, and by whom all work should be inspected, such expert to have been examined and approved by the American Society of Civil Engineers. The inspector was also to visit the scene of any accident, so called, and to ascertain, as far as possible, the cause. Messrs. T. C. Clarke and Julius W. Adams believed that in the present state of public opinion the above method would be impracticable, and feared that if inspectors were appointed it would be by political influence, and that the result would be worse than at present, as the inspectors would be inefficient, and yet to a great extent would relieve the owners of bad bridges from legal responsibility. They held that the best that could be done would be to provide means, in case of disaster, to fix plainly the responsibility, and recommended, first, that the standard for strength fixed by the society should be the legal standard, and in case it should be found that any bridge was of less strength than this, it should be taken as *prima facie* evidence of neglect on the part of the owners; second, that no bridge should be opened to the public until a plan, giving all dimensions, strains and loads, sworn to by the designers and makers, and attested by the corporation having control of it, had been deposited with the American Society; and, further, that the principal pieces of iron in the bridge should be stamped with the name of the maker, place of manufacture and date. Messrs. A. P. Bollen and Charles Macdonald looked rather toward effecting the desired result by so directing public sentiment by keeping the correct standard for bridges before it, that it would eventually compel the passage of the necessary laws.

Whether it is possible, in this country, to make an appointment dependent purely upon honesty and capacity, and free from political influence, may well be doubted. The examination before the expert committee of the American Society of Engineers would seem to be an excellent idea, and would be pretty sure to keep the number of applicants down to a pretty low figure. In case such a plan was found feasible let the State appoint a single person as inspector of roads and bridges, or State engineer. Pay him for his whole time, and let him give his whole time to the work, for he will need to do it. Such person should have in his possession a complete set of plans of every bridge of importance in the State, with all the computations of its strength, and as complete a history of each structure from its commencement as can be made up, all this to be supplemented by periodic examinations.

If, from such records, we find that a bridge was made of ordinary green timber twenty-five years ago, and that it has been getting rotten ever since, that it has rods of common merchant iron that was bought by some person not especially acquainted with the business, from an unknown firm, we had better pull it down before it falls

If, from such records, we find an iron bridge built twenty-five years ago, by an unknown company, with iron at best of a doubtful quality, and having a factor of three or four for the rolling stock and speeds of twenty years ago, instead of a factor of six for the rolling stock and speeds of to-day, we had better remove that bridge before it removes itself.

Such a record would be the property of the State, always accessible to anyone, and would be handed down so that the knowledge of one person would not expire with his term of office. No bridge should be erected in any State without first submitting the plans to the inspector, and receiving his approval, and depositing with him a complete set of the

plans and computations for the work. By this approval is not meant that the inspector is merely to give a favorable opinion as to the plan, but that he is to find as a matter of fact whether the proposed dimensions and proportions are such as will make a safe bridge; and just what a safe bridge is can be plainly defined by law as it is in Europe, and as it has been proposed by the American Society of Civil Engineers.

For example, if the law says that an iron railway bridge of one hundred feet span shall be proportioned to carry a load of three thousand pounds per lineal foot besides its own weight, and that with such a load no part shall be strained by more than ten thousand pounds per inch, all the inspector has to do is to go over the figures and see that the dimensions given in the plan are such as will enable the bridge to carry the load without exceeding the specified strains. When the work is erected the inspector must show that the plan has been exactly carried out, that the details are good, and proper evidence of the quality of materials used should also be given. Such inspection as this would at once prevent the erection of bridges like those at Ashtabula and Tariffville, and would save the public from such traps as those that fell at Dixon and at Groveland.

Perhaps the most difficult thing to do willbe to get satisfactory evidence in regard to the bridges that have been for a considerable time in use, and of which we do not know the history. This will be especially true in regard to the wooden bridges, of which there are so many about the country. Not only is it very difficult to be sure of the exact condition of the timber, but it is equally hard to tell anything about the iron. The Tariffville bridge fell on account of defective iron, and the defect was of such a nature as to defy any ordinary inspection.

What do we know to-day of the quality of the iron rods in any wooden bridge in Massachusetts? It is very doubtful if the best inspection we have in the United States at the present time would have found any defect so evident in the Tariffville bridge as to condemn it as unfit for the passage of trains. There are hundreds of exactly such bridges all over New England as far as we can tell by the best inspection we now have, made on the same plan, with no more material, and of which we know just as little of the quality of the iron as we did in the Tariffville bridge.

Of course we cannot expect to get a perfect system all at once. Any plan which would be proposed would no doubt be found more or less defective at first. We can hardly get a system worse than the one we now have, which allows forty bridges to break down every year. We may get a better one. To make the public see the need of such a system is the first step to be taken.

CORROSION OF IRON AND STEEL.

By M. L. GRUNER.

Translated from Annales des Mines for VAN NOSTRAND'S ENGINEERING MAGAZINE.

I.

In a previous note by the writer on the use of cast steel for rails, attention was called to the fact that moisture by favoring oxidation would hasten the wear of rails, and relying upon some experiments of M. Adamson, the belief was expressed that if soft steel rails wore less rapidly than hard steel, it must proceed in part from the greater liability to corrosion in steel that is more or less charged with a foreign element.

There remained some doubts as to the soundness of this conclusion, as M. Adamson had stimulated oxidation by acidulated water, instead of leaving it to the action of moist air.

Within the last year the writer has undertaken a series of experiments to determine the relative oxidizing effects of the different influences to which iron and steel are subjected in constructions and in the arts. The results of previous experiments have also been considered, especially those of the English engineers.

The question is not a new one. At

the suggestion of the British Association for the Advancement of Science, an extended series of experiments was performed by M. R. Mallet, of Dublin, to determine the durability of iron and steel structures when exposed to the prolonged action of air and water more or less pure. The results were published in the Association Reports of the years 1840 and 1843.

More recently the subject was reviewed, so far as it applied to the use of wrought iron and steel for hulls of vessels and for steam boilers, by the English Admiralty Board, and by two engineers, Messrs. D. Phillips and W. Parker. These results have been published, the first in the Reports of the Society of Civil Engineers, Vol. LXV., and the second in the Journal of the Iron and Steel Institute for May, 1881.

We shall see that the conclusions are in general accord with those of the writer, although regarded from a slightly different point of view.

The writer's experiments were made upon square plates measuring one decimeter on each side, cleaned and polished with lime and a dry grindstone. The weight varied according to the thickness, from 150 to 350 grammes, but as the surfaces were the same, the results obtained by the successive weighings may be directly compared.

In order to subject the plates to exactly the same conditions, they were fixed to the number of fifteen in a wooden frame, which was worked by a lever.

The frame was made of two strong vertical sides united by four horizontal cross pieces which were notched with a saw so as to hold the plates. The latter were therefore supported by the four corners in a manner which prevented reciprocal galvanic action.

The whole could be immersed simultaneously in a lead-lined trough containing the liquid designed to act upon the plates, or they could be suspended above the trough and exposed only to the moist air. The plates were placed parallel to each other and fifteen millimeters apart, thus forming together a sort of rectangular block with vertical compartments.

The first experiments were made in the winter of 1881–82 during a visit of the writer to the works of Saint Montan, near Beaucaire; some others at Paris, the last in Normandy near the sea, during the summer of 1882; all with the same apparatus.

The plates experimented upon were from different establishments. Eleven were supplied by M. Brustlein, Director of the Holtzer Steel Works at Unieux, near Firminy (Loire). Seven were furnished by M Alfred Evrard, Director of the old works of Verdie, Firminy, and ten by the son of the writer, who is Director of the Saint Montan Works near Beaucaire.

The Unieux plates were of pure crucible steel, unequally charged with carbon, but all containing small quantities of foreign elements, except two, one of which was a chrome, the other a tungsten steel.

The amount of carbon in the plates according to M. Brustlein was:

Plate No. 1 contained 0.40 per ct. of carbon.
Plate No. 2 contained
0.90 per ct. carbon { 0.022 manganese. / 0.006 phosphorus.
Plate No. 2 contained
0.90 per ct. carbon { 0.03—manganese. / 0.03—phosphorus.
Plate No. 3 contained 1.10 per ct. carbon.
Plate No. 4 contained 1.40 per ct. carbon.
Plate No. 5 contained 0.55 per ct. carbon, and 2 per ct. chromium.
Plate No. 6 contained 1.26 per ct. carbon, and 1 per ct. tungsten.

M. Brustlein adds that No. 2 was analyzed with care in the laboratory of M. Boussingault at Paris. Also that plates Nos. 1 to 4 belong to the variety of *tool* steel made at Unieux from Sweedish iron or from that of the Pyrenees. Nos. 1, 3 and 4 differ slightly from No. 2 in regard to containing manganese and phosphorus. The difference in amount of carbon is the chief difference in composition. The silicon is below one thousandth. Nos. 5 and 6 contain besides chromium and tungsten, a little more manganese than the others, and a slightly stronger trace of silicon. All the specimens were practically free from sulphur, and all are steels of the first quality.

Considering furthermore that four of the plates tempered at Unieux were from the same ingots as Nos. 1, 3, 4 and 5, and fearing that the others had also been partially tempered during the rolling

process, it was considered expedient to heat them to a dull red in a closed crucible, before subjecting them to the oxidizing tests.

The samples from Verdie, although made by the Martin-Siemens process were remelted in a crucible to render them more homogeneous. Nos. 1, 4 and 6 were remelted only. Nos. 5 and 7 were treated with wood charcoal to increase the charge of carbon.

The composition of these plates, according to M. Evrard, was for 100 parts of steel as follows:

Specimen No.	Carbon.	Manganese.	Sulphur.	Phosphorus.	Silicon.
1	0.160	0.140	0.048	0.039	0.093
2	0.450	0 160	0.044	0.037	0.139
3	0 600	0.150	0.022	0.034	0.186
4	0.800	0.140	0.027	0.034	0.279
5	0.900	0.110	0.025	0.033	0.186
6	1.400	0.110	0.033	0.030	0.372
7	1 560	0.120	0.020	0.032	0.320

It may be seen therefore, that these steels are as pure as those of Unieux, except that Nos. 6 and 7 contain a little more silicon by reason of remelting in earthen crucibles.

Before subjecting these plates to the oxidizing processes, they were treated to a reheating as in the preceding case, to avoid inequalities of hardness acquired at the time of rolling.

The steels from Chatillon and Commentry, unlike those of Firminy, are of an ordinary kind for rails and plates. Three of them from Saint Montan were obtained from a Bessemer converter. They are hard steel for rails. Two of the specimens from Montluçon were made by the Martin-Siemens process, and were soft steel designed for plates.

The five specimens yielded to analysis the following constituents:

		Carbon.	Manganese	Silicon.
Steel of Montluçon.	No. 1	0.21	0.28	0.09
	No. 2	0.17	0.21	0.13
" " St. Montan	No. 1	0.26	0.36	0.24
	No. 2	0.55	0.72	0.56
Hard steel of St. Montan..		0.59	1.36	0.93

The last specimen was quite impure, and was admitted by accident.

The experiments in oxidation included besides the steels, four specimens of cast iron of very different composition.

1st. A casting direct from the ore at Saint Montan from a charge designed for Bessemer steel rails. It is very graphitic, black, and obtained by working at high temperature, with a strongly calcareous slag. It contains 3 to 4 per cent. of manganese, 1 to 2 per cent. of silicon, and very little sulphur or phosphorus.

2d. A very pure cast iron from an old ship cannon, made in a reverberatory furnace with wood, at Ruelle, in 1845. It is compact, tenacious, and of a gray color. To obtain the specimen, a fragment was remelted in a crucible.

3d. Ordinary gray iron for pots, of slight tenacity, and containing little phosphorus; also remelted.

4th. White specular iron from Saint Montan containing 20 to 25 per cent. of manganese.

It was necessary to cast the plate about a centimeter thick in order to resist the action of the dry grinding. For this reason the weights of the cast plates are in some cases about double those of some of the steel specimens, but the exposed surface are made the same.

1. Action of Moist Air.

1st. Frequent but brief immersions in water with long exposure to the air.

Passing now to the experimental results, we consider first those obtained by causing rust by frequent short immersions in water at ordinary temperatures, and alternate free exposure to the atmosphere.

At the time of the first experiments, which were unfortunately too brief, being of ten days' duration only, the plates were wet with fresh water. The results were not striking. The influence due to the variable character of the plates was hardly sensible. This experiment is to be repeated, and will be prolonged through several weeks. In the meanwhile, the results obtained in this first experiment, made in Normandy, between the 5th and 15th of September, 1882, are here given.

It may be added that to facilitate cleansing, the plates were dipped on the last day in water acidulated with $\frac{1}{4}$ per

cent. of sulphuric acid of 66 "Beaume," after which they were brushed, then rapidly dried, and finally weighed.

TABLE A.

Origin of plates.	No.	Original wt.	Final wt.	Loss.	Remarks.
		grs.	grs.	grs.	
Annealed steel from Holtzer Works.	1	300.5	299.2	1.3	
	2	324.4	323.5	0.9	
	2a	331.9	329.2	2.7	
	3	304.2	303 0	1.2	
	4	320.8	318.2	2.6	High steel.
	5	338.5	336 0	2 5	Chrome steel.
	6	339.0	337.7	1.3	Tungsten steel.
Hard steel from Holtzer Works.	1	313.9	312.5	1.4	The numbers correspond to the annealed plates.
	3	291.1	289.0	2.1	
	4	326.5	324.5	2.0	
	5	333.2	331.5	1.7	
Soft steel from Montluçon	1	149.9	149.0	0.9	
	2	161.4	160 0	1.4	
Hard steel from St. Montan.	1	282.2	280.5	1.7	
	2	357.5	356.2	1.3	

The only conclusion to be drawn from the above results is, that the rusting due to moist air attacks all steels nearly alike whatever their degree of carbonization or their purity, and moreover, that the temper of the steel does not seem to modify in a sensible degree the liability to corrosion.

2d. Short but frequent immersions in acidulated water; long exposure to the air.

The same plates were subjected to action of exposure to air after immersion in water containing ½ per cent. of concentrated sulphuric acid. The immersion lasted ten minutes. They were taken out as soon as hydrogen was set free to any sensible degree. The exposure to the air continued from six to ten hours, and then they were immersed anew for some minutes. After five days the acidulated water was renewed, and the previous operations were repeated for eleven days, so that the total duration of the experiment was sixteen days (May 29th to June 13th).

At the end, the plates were submerged for two or three hours in the bath which had been used for the last eleven days.

The following results were obtained:

TABLE B.

Origin of plates.	No.	Original wt.	Final wt.	Loss.	Remarks.
		gr.	gr.	gr.	
Annealed steel from Holtzer works.	1	311.3	307.0	4.3	
	2	334.9	330.5	4.4	
	2*bis*	342.3	338.8	3.5	
	3	315.3	311.0	4.3	
	4	331.0	327.5	3.5	
	5	351.2	345.4	5.8	The chrome steel cleanses readily, yielding a gray, greasy deposit.
	6	348.3	345.3	3.0	
Tempered steel from Unieux.	1	326.3	320.2	6.1	
	3	304.1	297.3	6.8	
	4	340.8	334.1	6.7	
	5	344.1	339.1	5.0	
Soft steel from Montluçon	1	157.3	152.5	4.8	
	2	169.7	165.8	3.9	
Hard steel from St. Montan	1	292.6	287.8	4.8	
	2	369.2	364.6	4.6	

As in the preceding experiments, we see that the hardness of the steel has little or no influence on the liability to rust. We can only state that tempered steels, with the exception of chrome steel, are more strongly attacked than the same steels annealed; that among the untempered steels, chrome steel is the most affected, and tungsten steel the least. We shall see that these differences should be attributed to the acid, for in the experiments in which acidulated water alone acts, there being no lengthened exposure to the air, the chrome steel is most acted upon, and the tempered steels suffer more than the untempered ones.

The same method of immersion in acidulated water and subsequent exposure to the air has been applied to the steel plates from Verdié; the steels charged with manganese and silicon from St. Montan, and to the four cast-iron plates above mentioned, one experiment continued five days, the other twenty.

For the first experiment, which lasted from the 15th to the 20th of March, the water contained ½ per cent. of sulphuric acid, which was renewed on the second, and again on the fourth day so as to excite energetic action.

In the second experiment the solution contained at first only ¼ per cent. of acid. On the sixth day this was increased to ½ per cent., but the bath was renewed only twice during the last fifteen days, in order that the oxidizing action might be less intense.

The results of the first of these experiments are as follows:

TABLE C.

Origin of plates.	Nos.	Original weight.	Final weight.	Loss.	Remarks.
		gr.	gr.	gr.	
Annealed plates from Verdié	1	245 0	242.3	2.7	
	2	266.8	263.8	3.0	
	3	268.5	265.8	2.7	
	4	283.1	280.6	2.5	
	5	265.0	262.5	2.5	
	6	295.5	294.0	1.5	Strongly carbonized. The coatings more easily remov'd.
	7	273.0	270.7	2.3	
Steel from St. Montan containing silica and manganese.	*	265.6	363 6	2.0	These plates cleaned easily, especially the tempered one, which deposited a soft coati'g
	†	369.5	367.0	2.5	
Black pig iron for Bessemer steel.	1	315.5	311.6	3.9	Promptly attacked by the acid, leaving a graphited'pos't
Charcoal pig for cannon.	2	337.9	336.0	1.9	
Gray pig for pots.	3	394.0	391 3	2.7	Not so readily attacked as No. 1.
Manganese pig iron fr'm St. Montan.	‡	726.2	723.4	2.8	

* Untempered. † Tempered. ‡ White crystalline.

As in the preceding cases, these steels exhibit but slight differences as regards liability to oxidize.

Apart from the black pig iron, and the manganese iron from Saint Montan, the irons are not more corroded than the steel plates. The charcoal iron from Ruelle is the least oxidized. The specular iron, although containing 20 per cent. of manganese, is relatively but slightly affected, the carbon seeming to protect the metal. The black cast iron is, on the contrary, easily oxidized, partly from its porosity, and partly, without doubt, owing to the contained silicon.

The second experiment, continued through twenty days, gave results as exhibited in the next table.

TABLE D.

Origin of plates.	Nos.	Original weight.	Final weight.	Loss.	Remarks.
		gr.	gr.	gr.	
Annealed steel from Verdié forge.	1	242.0	238.0	4.0	The steels act nearly alike; the coating is easily removed. Under the rust is a gray, unctuous coating.
	2	263 7	259.4	4.3	
	3	265.4	260.8	4.6	
	4	280.0	275.2	4.8	
	5	261.8	257 1	4.7	
	6	292.5	288.1	4.4	
	7	269.9	265.3	4.6	
St. Montan steel with silicon and manganese	*	362.0	358.2	3.8	Black coating under the rust.
	†	362.9	358.1	4.8	
Black pig iron from St. Montan.	1	295.7	291.6	4.1	No. 1 was easily cleaned of rust. A black coating of graphite beneath.
Charcoal pig iron from Ruelle	2	335.2	331.9	3.3	
Gray pot metal.	3	382.4	379.5	2.9	
Manganese iron of St. Montan.	‡	721.9	720.0	1.9	

* Untempered. † Tempered. ‡ White crystalline.

The differences are less pronounced than in the preceding case, by reason of the less amount of acid in the bath. The conditions more nearly resemble those of the earlier experiment in which moist air alone was the oxidizing agent.

It will be seen here that as in the preceding cases, tempering favors oxidation.

The iron plates resist oxidation rather better than the steel, the manganese, *spiegel* iron being less corroded than any of the others.

II.

ACTION OF FRESH WATER AND SEA WATER.

Following the experiments made under the influence of moist air, were conducted some in which oxidation depended upon fresh water and salt water respectively.

It is well known that pure water will attack iron, neither at the ordinary temperatures nor at the heat of boiling water. But oxidation is after a time produced under the combined action of the air and carbonic acid dissolved in the feed water of boilers.

In order to properly measure the effect of fresh water, a prolonged immersion is evidently necessary. Now the only experiment made upon our plates was continued only eleven days. It was manifestly insufficient, but even this short period was enough to show that the iron plates appear to disadvantage when compared with steel in fresh water. The manganese irons particularly yielding with great readiness and exhibiting a covering of black rust. Thus while the steel specimens have lost at the maximum only 0.gr.3 in eleven days, the loss of the black cast iron of Saint Montan was 0.gr.7, and of the spiegel iron 1.gr.5 Then follows the charcoal iron 0.gr.6, and the phosphorus iron (hot metal) with 0.gr.3.

The steel plates furthermore were only slightly reddened on the parts near the surface of the water, while the two manganese plates were entirely covered wit a flocculent dark rust.

But although fresh water acts slowly, sea water acts with great energy. A chloride of iron was observed to form on the first day of exposure, and this was soon followed by flakes of oxide. A li tle hydrogen was seen to escape, and the iron plates were covered with a black rust.

The experiment continued nine days. and the water was renewed three times. The results of the action of sea-water are shown in Table E, preceding column.

It is readily seen by Table E that sea-water, like fresh water, attacks the irons more readily than the steels, and that of the four iron specimens it is the manganese iron which is most corroded. The difference is great and contrasts singularly with the action of humid air, which attacks the manganese iron with less vigor than the three others.

In comparing the two tables D and E, it may be remarked that while sea-water attacks the gray phosphureted iron quite strongly, fresh water and moist air act upon such iron less readily than upon the other varieties.

TABLE E.

Origin of plates.	Nos.	Original weight.	Final weight.	Loss.	Remarks.
		gr.	gr.	gr.	
Annealed steel from Verdié.	1	234.8	232 7	2.1	
	2	256.8	254.8	2 0	
	3	258.0	256.9	1.1	
	4	272.5	270.3	2.2	
	5	253.9	252.7	1.2	
	6	285.3	283.3	2.0	
	7	262.0	260.2	1.8	
St. Montan containing manganese and silicon.	*	354.2	351.2	3.0	A black unctuous deposit under the rust.
	†	350.8	348.0	2.8	
Black pig iron, St. Montan.	1	280.4	276.9	3.5	On all the iron plates a black carbon deposit under the rust.
Charcoal iron of Ruelle.	2	326.9	323.8	3.1	
Gray cast iron.	3	371.7	366.7	5.0	
Specular iron.	‡	719.0	712.0	7.0	

* Soft. † Tempered. ‡ White crystalline.

TABLE E'.

Origin of the plates.	No.	Original wt.	Final wt.	Loss.	Remarks.
		gr.	gr.	gr.	
Annealed steel from Holtzer Works.	1	305 0	301.9	3.1	
	2	328.5	326.1	2.4	
	2a	336.8	334.7	2.1	
	3	309.0	305.8	3.2	
	4	325.5	322.8	2.7	
	5	343.3	340.3	3 0	Under rust of No. 5 dark gray deposit.
	6	343.4	341.8	1.6	
Tempered steel from Holtzer Works.	1	318.2	315.7	2.5	
	3	295.3	293.3	2.0	
	4	332.1	329.7	2.4	
	5	337.1	335.9	1.2	Faint gray coating
Soft steel of Montluçon	1	150.5	149.9	0.6	
	2	163.8	161.9	1.9	
Hard steel of Saint Montan.	1	287.8	284.5	1.3	
	2	362.6	360.0	2.6	

One other anomaly is noticeable, it is that tempered steel seems less corroded by sea water than the same steel untempered, while tempering invites the action of acidulated water.

The fifteen plates of steel from Unieux were also subjected to the action of sea water. The experiment lasted seventeen days. The water was renewed but once. At the end of the period the plates were treated for an hour with a $\frac{3}{4}$ per cent. solution of acid for the purpose of removing the rust coating.

The results are herewith given. (See Table E', page 215.)

This experiment, like the preceding, shows that the action of sea water is the reverse of that of acidulated water upon tempered steel. The tempered plates are less acted upon than the untempered.

Annealed chrome steel is more corroded than carbon steel, while tempered chrome steel is affected less. Comparison of the steels of Montlugon and Saint Montan proves that the soft steels are less corroded by sea water than hard ones, which accords with the results of the trial of acidulated water, while moist air affected both to nearly the same degree.

DIMENSIONS OF TALL CHIMNEYS.

By L. PINZGER.

Translated from Revue Universelle des Mines for VAN NOSTRAND'S ENGINEERING MAGAZINE

THE formula frequently employed for the determination of the height of a chimney is:

$$u_a = \varphi\sqrt{2gh\frac{T_m - T_o}{T_o}},$$

in which U_a is the velocity of the escaping gases; $T_o = 273 + t_o$, the absolute temperature of the exterior air; $T_m = 273 + t_m$, the absolute mean temperature of the gases in the chimney (t_o and t_m being expressed in centigrade degrees); $g = 9.81$, the acceleration of gravity, and φ a coefficient of correction relating to the resistances opposed to the motion of heated gases.

M. Grashoff, in 1866, propounded a theory which renders it easy to take account of the causes which modify the movements of the products of combustion; more recently he has introduced a *résumé* of this theory in his work; *Construction des Machines.*

While the results thus obtained are mathematically accurate, they have not yet taken a convenient form for practical use; partly because the principles of the mechanical theory of heat have not been generally adapted to the calculation of the movement of gases, and partly in consequence of the complex character of the formulas.

Thus the height h of the chimney cannot be deduced directly in terms of the other quantities; it is necessary to resort to approximate methods. In order to simplify the calculations, M. Grashof has constructed tables adapted for use in the case of chimnies and temperatures such as are commonly employed in practice. He has also established easy empirical formulas deduced from exact theory.

The writer proposes to briefly review the principles involved, and then to develop a method of calculation which shall possess the precision of Prof. Grashof's, but which will afford an easy practical formula.

The special function of a chimney is to cause a sufficient quantity of air to traverse the mass of fuel spread over the grate to insure its combustion—to make the hot gases circulate through conduits where they part with a portion of their heat—and finally to discharge these gases into the atmosphere with a velocity which shall diminish as much as possible the action of the wind upon the draft.

When the products of combustion are deleterious to health or vegetation, it becomes necessary to employ high chimneys, so that these products shall reach the earth only after being mixed with a large volume of air.

The cause of the draft lies in the difference of pressure in the gases in the fire, the flues, the shaft and that of the outside air at the level of the grate.

Let p_0 be the atmospheric pressure in kilograms per square meter at the level of the grate; p_1, p_2, p_3 and p_4 the pressures in the fire, at the entrance to the flue; at the outlet from the flue; in the horizontal shaft and at the base of the chimney; then we ought to have $p_0 > p_1 > p_2 > p_3 > p_4$ so as to insure draft.

It is necessary then, 1st, to obtain such a pressure p_4 at the base of the chimney as would be produced by a current of air required for the combustion; and 2d, to force the gas to the height of the chimney and discharge it with sufficient velocity.

The difference of pressure $p_0 - p_1$ cannot be determined by theory alone, but the direct measure of it is obtained by the manometer. In stationary furnaces this difference corresponds to a water column of 3 to 20 millimeters, according to the thickness of the layer of fuel. In locomotives it may be as high as 100 millimeters. As the weight of a column of water having a base of one square meter and a height of one millimeter is one kilogram, it follows that $p_0 - p_1$ may be equal from 3 to 20 kilograms per square meter.

If we let h_0 represent the height of a column of air of the temperature T_0 of which the weight upon one square meter of base is $p_0 - p_1$, we shall have

$$(1) \qquad h_0 = RT_0 \log. \left(\frac{p_0}{p_1}\right)$$

R expressing the constant of the equation of gaseous condition, $pv = RT$. R being equal to 29.3 for atmospheric air, more or less humid.

In taking $p_0 = 1000^k$ per square meter under average conditions of barometric pressure, and $T = 273 + 17 = 290$, a column of air of $h_0 = 4^m.25$ to 17^m will be equal to the pressure above mentioned.

The height h_0 will depend upon the quantity of the fuel burned in a unit of time—the thickness of the layer of fuel and upon the weight of the products of combustion.

Grashof assumes for the heat of soft coal the value $h_0 = 25\, G_1 \Delta^3$ in which G represents the quantity of gas produced by the combustion of 1 kilogram of fuel, and Δ the thickness of the layer of fuel.

If $G_1 = 22$ kilograms and $\Delta = 0^m.1$, we have:

$$h_0 = 25 \times 22 \times 0.01 = 5^m.50.$$

We may by this calculation find with sufficient exactness the values of the differences of pressure $p_1 - p_2$, $p_2 - p_3$ and $p_3 - p_4$. Taking into consideration the relations existing between different systems of heating and of flues, we find:

$$\log \left(\frac{p_1}{p_2}\right) = \frac{1}{RT_0}(1+\zeta_2)\frac{u_0^2}{2g} \cdot \frac{T_2}{T_0}.$$

$$\log \left(\frac{p_2}{p_3}\right) = \frac{1}{RT_0}\frac{u_0^2}{2g}$$

$$\left\{\lambda \frac{l}{d}\left(\frac{Q}{kFT_0}\right) + \frac{T_k}{T_0}\right) - 2\frac{T_2 - T_3}{T_0}\Bigg\}$$

and $$\log\left(\frac{p_3}{p_4}\right) = \frac{1}{RT_0}\zeta_3 \frac{u_0^2}{2g}\frac{T_3}{T_0}, \quad \text{whence}$$

$$RT_0 \log\left(\frac{p_1}{p_4}\right) = \frac{u_0^2}{2g}\left\{\frac{(1+\zeta_2)T_2 + \zeta_3 T_3}{T_0}\right.$$

$$\left. + \lambda \frac{l}{d}\left(\frac{Q}{kFT_0} + \frac{T_k}{T_0}\right) - 2\frac{T_2 - T_3}{T_0}\right\}.$$

$RT_0 \log \frac{p_1}{p_4}$ expressing equally the height h_1 of a column of air at the exterior temperature T_0, subjected to the pressures p_1 and p_4 upon the lower and upper bases, and of which the weight measures the pressure $p_1 - p_4$ on a square meter. Consequently

$$(2) \quad h_1 = \frac{u_0^2}{2g}\left\{\frac{(1+\zeta_2)T_2 + \zeta_3 T_3}{T_0} + \right.$$

$$\left. \lambda \frac{l}{d}\left(\frac{Q}{kFT_0} + \frac{T_k}{T_0}\right) - 2\frac{T_2 - T_3}{T_0}\right\}.$$

In this equation u_0 represents the velocity with which the heated gas passes the section f of the flues if they have the temperature T_0; T_2 and T_3 are the temperatures at the escape from the flue; T_k the absolute temperature (of water in a steam boiler); l the length of the flues; d their mean diameter $= \frac{4f}{P}$; (P being the perimeter and f the section); F the heated surface of the boiler; Q the quantity of heat transmitted by this surface every hour; k the coefficient of conductivity of the surface for heat, which for boilers is about 20; ζ_2 and ζ_3 the coefficients of correction relating to the sudden changes in diameter and direction; (in steam boilers $\zeta_2 = 1.5$ to 25, and

$\zeta_2 = 0.8$ to 1); λ the coefficient of friction in the flues (=0.08).

Between the quantities F, Q, T_2, T_3 and

$$(A)\quad T_2 = T_k + (T_3 - T_k)e^{-\frac{kF}{Gc}}$$

$$(B)\quad Q = Gc(T_2 - T_3)$$

in which G expresses the weight of the gases flowing through each section of the flues per second, and c is the specific heat, of which the mean value is 0.25 for bituminous coal fuel.

The weight of a column of air of the external temperature T_0 and a height $h_0 + h_1$, representing the difference of pressure $p_0 - p_4$ per square meter, the point is to determine the height h above the level of the grate to which the gases can be raised in the atmosphere. This would be the height for the chimney.

In this calculation there should be taken into account; 1st, the diminution of atmospheric pressure due to the height h; 2d, the diminution of the pressure of gas for the same height; 3d, the mechanical work consumed by the ascent of the gas through this height; 4th, the velocity of the escaping gas at the top of the chimney. This outflow cannot evidently take place unless the pressure on the escaping gas is at least equal to the atmospheric pressure.

In order to calculate the upward velocity of the gases in the chimney, we make use of the equation

$$\frac{udu}{g} = -ds - RT\frac{dp}{p} - \lambda\frac{ds}{d_m}\frac{u^2}{2g},$$

in which p is the pressure at the top of the chimney and d_m is the mean diameter.

If we represent by u_4 T_4 and p_4 respectively, the velocity, the absolute temperature and the pressure of the gas at the base of the chimney; also by u_a T_a and p, the same quantities at the upper outlet of the chimney; the integration of the preceding equation, if we take $T_m = \frac{1}{2}(T_4 + T_a)$ for the mean temperature of the chimney, also $u_m = \frac{1}{2}(u_4 + u_a)$ for the mean velocity, will give for the term relating to the resistance of friction

$$\frac{u_a^2 - u_4^2}{2g} + \lambda\frac{h}{d_m}\frac{u_m^2}{2g} + h = RT_m \log\left(\frac{p_4}{p}\right).$$

On the other hand we shall have for the height h of a column of air, at the temperature T and under the upper and lower pressures of p_0 and p,

$$h = RT_0 \log\left(\frac{p_0}{p}\right).$$

Combining the preceding equations we get:

$$RT_0 \log\left(\frac{p_0}{p_4}\right) = h\,\frac{T_m - T_0}{T_m} - \frac{T_0}{T_m}\cdot \left\{\frac{u_a^2 - u_4^2}{2g} + \lambda\,\frac{h}{d_m}\cdot\frac{u_m^2}{2g}\right\}.$$

The first number of this being only the value of $h_0 + h_1$, the height of the chimney will be given by the formula:

$$(3)\quad h = (h_0 + h_4)\frac{T_m}{T_m - T_0} + \frac{u_a^2}{2g} \left\{1 - \left(\frac{u_4}{u_a}\right)^2 + \lambda\frac{h}{d_m}\left(\frac{u_m}{u_a}\right)^2\right\}\frac{T_0}{T_m - T_0}$$

in applying which to find approximate values of h, the following hypothesis is employed:

From the fundamental equation $pv = RT$, and from the equation $fu = G'v$ we deduce

$$u = G'R\frac{T}{pf},$$

G being the weight of gas in kilograms which passes each section of the chimney in a unit of time with the velocity u.

The influence of the change of pressure p upon the variation of the velocity u is so small that we may neglect it, while we have to regard the influence of change of temperature and of cross section, and we have with sufficient exactness:

$$\frac{u_4}{u_a} = \frac{T_4}{T}\frac{f_a}{f_4}$$

and

$$\frac{u_m}{u_a} = \frac{1}{2}\left(\frac{u_4}{u_a} + 1\right).$$

We can calculate from equation (3) a first approximate value of h, after having assigned proper values to f_a f_4 and f_m, also to T_a according to the value of T_4 and according to the material of which the chimney is built. It is necessary also to determine $\frac{u_4}{u_a}$ and $\frac{u_m}{u_a}$, since in the term $\frac{h}{d_m}$ we substitute the approximate value $(h_0 + h_1)\frac{T_m}{T_m - T_0}$.

From this value of h a more exact value of T_a can be deduced by employing the equation

$$T_a = T_0 + (T_1 - T_0)e^{-\frac{k_s F_s}{G_s c}}$$

in which k_s represents the coefficient of conductivity of heat for the sides of the chimney; F_s the area of the interior surface; G_s the weight of gas per hour passing any section of the chimney; $c=0.25$, the specific heat of the gaseous mixture.

For chimneys of masonry, we take $K_s = 1.4$ to 2 according to the thickness of the sides. For chimneys in plate or sheet iron $k_s = 6$; $G_s = 22B_n$; B_n being the weight of coal consumed per hour on all the grates whose fires lead to the same chimney.

From this value of T_a we easily deduce more exact values of T_m, $\frac{u_1}{u_a}$ and of $\frac{u_m}{u_a}$. We shall then be able to obtain a second approximate value of h, which may be regarded as a definite value.

We shall have for the magnitude of f_a, the entrance to the chimney,

$$f_a = \frac{G_s u_a}{3600\, u_a}$$

or

$$f_a = 0.062 \frac{T_a}{u_a} \cdot \frac{B_n}{3600}.$$

In calculating $\frac{f_a}{f_1}$ there are three cases to be considered:

1st. The transverse section of the chimney decreases from the bottom upwards; $f_a < f_1$. (Fig. 1.)

2d. The transverse section is everywhere the same; then $f_a = f_1$. (Fig. 2.)

3d. The section increases from below upwards; then $f_a > f_1$. (Fig 3.)

When f_a is less than f_1, the ratio varies from 0.40 to 0.64 for chimneys constructed either in masonry or iron according to height. We may take therefore as a mean value $\frac{f_a}{f_1} = 0.52$.

The second condition of course gives $\frac{f_a}{f_1} = 1$.

For the third case we take $\frac{f_a}{f_1} = 1.5$.

With regard to the temperatures T_1 and T_a we may introduce as first values in the calculation

$$\frac{T_1}{T_a} = 1.06 \text{ for chimneys in masonry.}$$

and $\frac{T_1}{T_a} = 1.10$ for iron chimneys.

For the velocity u_a with which the gas ought to escape from the chimney, we should take a rather large value for fear of interference by downward currents of air. The value of u_a should never be less than two meters.

Suppose that to calculate the dimensions of a masonry chimney, we admit that $\frac{T_1}{T_a} = 1.06$. We shall then obtain the following values:

For the first type, (Fig. 1)

$$\frac{u_1}{u_a} = 1.06 \cdot 0.55 = 0.55; \quad \frac{u_m}{u_a} = 0.775$$

thus

$$h = (h_0 + h_1)\frac{T_m}{T_m - T_0} + \frac{u^2 a}{2g}$$

$$\left\{ \lambda \frac{h}{d_m} \cdot 0.6 + 0.7 \right\} \frac{T_0}{T_m - T_0}$$

for the second type, (Fig. 2)

$$\frac{u_1}{u_a} = 1.06; \quad \frac{u_m}{u_a} = 1.03$$

then

$$h = (h_0 + h_1)\frac{T_m}{T_m - T_0} + \frac{u^2 a}{2g}$$

$$\left\{ \lambda \frac{h}{d_m} \cdot 1.06 - 0.24 \right\} \frac{T_0}{T_m - T_0};$$

for the third type, (Fig. 3)

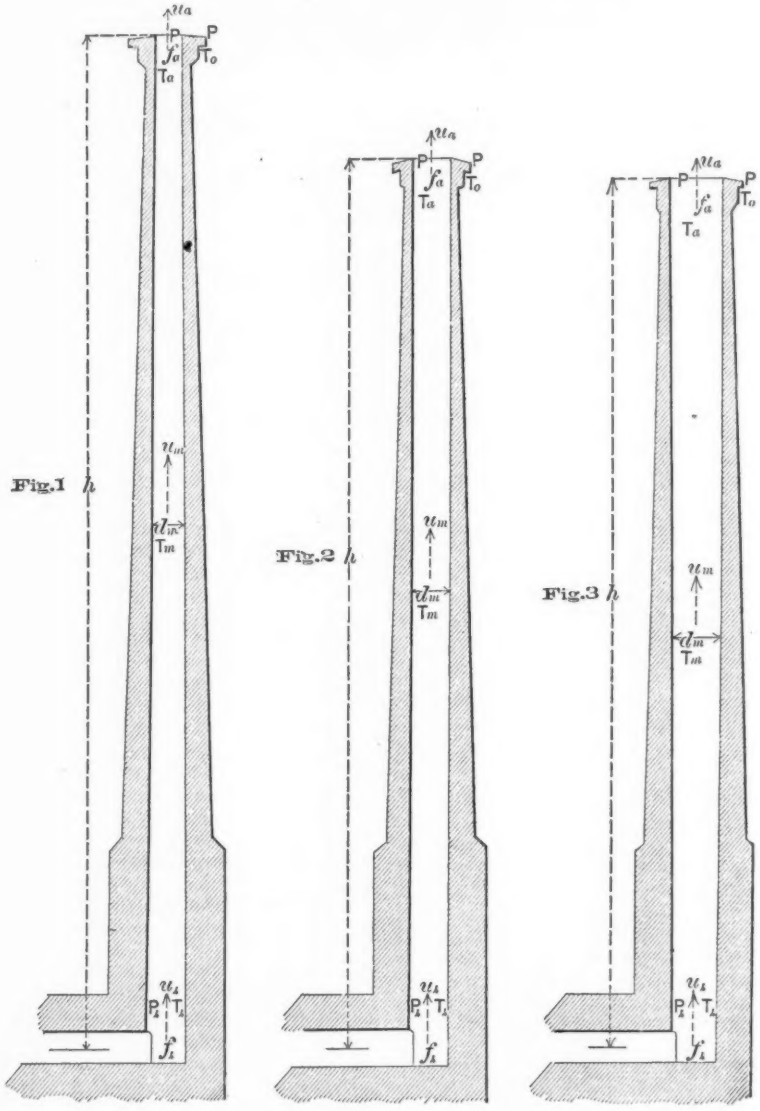
$$\frac{u_1}{u_a} = 1.06 \cdot 1.5 = 1.59; \quad \frac{u_m}{u_a} = 1.3;$$

then

$$(h = h_0 + h_1)\frac{T_m}{T_m - T_0} + \frac{u^2 a}{2g}$$

$$\left\{ \lambda \frac{h}{d_m} \cdot 1.7 - 1.53 \right\} \frac{T_0}{T_m - T_0}.$$

It is easy to see that for all forms the total height of the chimney depends; 1st, upon the amount of resistance encountered by the gases in the flues and through the fuel; 2d, upon the velocity of escape of the gases. The second term is very small compared with the first, and as the variation of h for one type or the other depends on the second term, it is evident that the employment of type No. 3 can-



not lead to a notable diminution of the height which it is necessary to use in No. 1. On the contrary the height becomes even less for the chimney contracted in the upper part than for the cylindrical form or for that which enlarges upwards; if it is demanded that the velocity of escape of the gases u_a be the same for the three types, the reason is that for the first form the resistance due to friction is more feeble. The fact should not be lost that in consequence of the large value of u_i for the 3d type compared with the value of the same function

for the 1st type, that the specific pressure p_1 would be much less in the first case than in the second; consequently the enlargement of the chimney towards the top would occasion a stronger current of hot gases at the bottom.

If on the other hand we desire that the value of u_1 be the same for the three types, for equal ratios of temperatures and pressures, we shall have for the chimneys:

Fig. 1, $u_a = 1.82\, u_1$,

Fig. 2, $u_a = 0.94\, u_1$,

Fig. 3, $u_a = 0.63\, u_1$.

Let for example, for the

1st form $u_a = 4$ meters

consequently $u_1 = 2^m.2$.

Let in 2d form $u_a = 2^m.07$

and in 3d form $u_a = 1^m.39$

With this feeble velocity of escape, the draft of the chimney would be easily reversed by the wind.

Take as an example a brick chimney designed to discharge the products of combustion from three boilers of equal size. Allowing for each boiler a heating surface of 60 square meters, and requiring a consumption of 100 kilos of coal per hour; the length of the flues being 30 meters, and their mean cross section $f = 0.2$ sq. meter; we have $d = \frac{4f}{P} = 0.^m25$.

Let $T_2 = 1300°$; $T_k = 420°$; $G = 2200^k$, we shall have according to (A)

$$T_3 = 420 + (1300 - 420)\, e^{-\frac{10.60}{2200.0,25}} = 520°;$$

and according to (B)

$$Q = 2200 \times 0.25(1300 - 520) = 429000^c.$$

(The heat directly radiated not being included.)

For $T_0 = 280°$ we shall have:

$$u_0 = \frac{Gv}{3600 f} = \frac{2200 \times 0.8}{3600 \times 0.2} = 2^m.45$$

and according to equation (2):

$$h_1 = 0.306 \left\{ \frac{3 \times 1300 + 1 \times 520}{280} + 0.08 \frac{30}{0.25} \left(\frac{429000}{20 \times 60 \times 280} + \frac{420}{280} - 2\, \frac{1300 - 520}{280} \right) \right\} = 11^m.3.$$

Assuming $h_0 = 5^m.5$ we shall have:

$$h_0 + h_1 = 16^m.8.$$

Since the heated gases are cooled in passing through the horizontal conduit, we shall have to admit that the absolute temperature T_4 is only 500° at the base of the chimney; whence

$$T_a = \frac{500}{1.06} = 470° \text{ and } T_m = \tfrac{1}{2}(500 + 470) = 485°$$

We will take the velocity of escape of the gas, $u_a = 6$ meters, so that when only one boiler is used the velocity will be 2 meters; we then have:

$$u_a^2 = 1^m.835,$$

and equation (4) gives:

$$f_a = 0.062 \frac{470}{6} \cdot \frac{300}{360} = 0.405 \text{ sq. meters},$$

$d_a = 0.718$, or nearly 0.72 meters.

In order to provide, in case of need for a fourth boiler, we will take:

$$f_4 = \tfrac{4}{3} f = 4 \times 0.2 = 0.8 \text{ sq. meters.}$$

then $d_4 = 1.0$ meter, and

$$d_m = \tfrac{1}{2}(1.0 + 0.72) = 0.86 \text{ meters.}$$

We now have

$$\frac{u_4}{u_a} = \frac{500}{470} \frac{0.405}{0.800} = 0.54 \text{ and } \frac{u_m}{u_a} = 0.77.$$

The first approximate value then is

$$h = 16.8 \frac{485}{485 - 280} + 1.835 \left\{ 0.08 . 0.593 \frac{46}{0.86} + 0.708 \right\} \frac{280}{485 - 280}$$

$$h = 39.665 + 8.133 = 47^m.798, \text{ say } 48 \text{ meters.}$$

We obtain more exactly

$$T_a = 280 + (500 - 280)\, e^{-\frac{1,6.180}{6600.0.25}} = 473°.$$

This result accords so well with the value 470° introduced above in the calculations of T_a, that it will not be necessary to make any correction in the estimated height of 48 meters.

We have $u_4 = 0.54 \times 6 = 3.24$ meters for the velocity with which the gas enters a chimney whose cross section diminishes upward. (Fig. 1.)

If a cylindrical chimney be used (Fig. 2) for which the velocity of escape $u_a = 0.94 \times 3.24 = 3.046$ meters, the height h will be reduced to:

$h = 39.665 + 0.473$

$$\left\{0.08\frac{42}{1.0}1.06 - 0.124\right\}\frac{280}{485-280}$$

$h = 39.665 + 2.221 = 41^m.886$, or 42^m.

For a chimney, wider at the top than the bottom, for which $\frac{f'a}{f_4} = 1.5$, we have $u_a = 0.63 \,.\, 3.24 = 2^m.04$ and

$h = 39.665 + 0.212$

$$\left\{0.08\frac{41}{1.12}1.7 - 1.53\right\}\frac{280}{485-\frac{485}{2\,?}}$$

$h = 39.665 + 0.999 = 40^m.664$, or 41^m.

The employment of the forms represented in figures 2 and 3 leads to a reduction in the estimated height of 6 or 7 meters, but the velocity of the escaping gases is reduced from 6 to 2 or 3 meters, which might lead to serious inconvenience when only one boiler is at work instead of three. In such a case a chimney of the third type, the velocity of the escaping gases would only be $\frac{2}{3}$ meter.

In order to diminish the downward action of the wind, the chimney may be surmounted by a conical cap. Many constructors do not approve of the widened top, although it allows of greater width to the orifice and therefore greater facilities for changing the direction of the currents of air at the summit of the chimney.

CENTRIFUGAL VENTILATORS FOR MINES.

By DANIEL MURGUE.

From Proceedings of the Institution of Civil Engineers.

Mine ventilators acting on the principle of a pump—known also as ventilators of varying capacity, or of displacement—formed the subject of two previous papers by the author, who is engineer of the Bessèges collieries in the department of Gard, in the south of France. Having subsequently acted as one of the three commissioners who reported upon the ventilation of the mines in that district, he is now able to make use of their report as a basis upon which to investigate the working of mine ventilators exhausting by centrifugal action. The characteristic features of centrifugal exhausting fans are—their extreme simplicity, whether revolving vertically or horizontally; the free passage for the air through them from the upcast shaft to the external atmosphere; and the large air-current they are capable of discharging from mines having large air-ways—all three of which are in marked contrast with the features distinctive of displacement ventilators.

Vacuum produced by Centrifugal Ventilators.—For investigating the theoretical efficiency of centrifugal ventilators in regard to the degree of vacuum they produce, the author recurs to his principle of "equivalent orifices." Thus, supposing the air-drift from the upcast shaft to the ventilating fan were closed by an air-tight sheet across its mouth, the revolving fan, though producing no current, would maintain an initial vacuum H in the confined space of the drift. If now an inlet orifice of area a be made in the sheet, the effective vacuum h of the current will be less than the initial vacuum H, by the amount of loss due to friction and eddies in the passage of the air current through the fan itself. Supposing the air discharged from the fan had to pass through an outlet orifice of area b in another sheet, presenting an obstruction equivalent to that encountered in its passage through the fan, then the obstructions presented to the ventilating current by the mine and by the fan respectively are replaced by two "equivalent" orifices, a and b, in two imaginary sheets, between which the fan works. The relation $\frac{H-h}{h} = \frac{a^2}{b^2}$ is readily deduced; whence the author arrives at the two general formulæ for the effective vacuum h, and for the effective volume V of air current per second: namely,

$$h = \frac{H}{1+\frac{a^2}{b^2}} \text{ and } V = \frac{0.65\, a\sqrt{2gH}}{\sqrt{1+\frac{a^2}{b^2}}}$$

where the vacuum h or H is measured

by the equivalent head or column of *air*, assumed at atmospheric pressure, and non-elastic within the usual small range of exhaustion produced by a mine ventilator.

Investigating next an expression for H, he shows that the vanes of any ventilating fan ought to become truly radial at their tips, instead of being inclined backwards; and that with the radial vanes $H=\frac{u^2}{g}$, where u is the velocity of the tips of the vanes, and the fan revolves within a casing having an expanding chimney, from which the air is discharged into the atmosphere with a velocity low enough to be neglected. Hence in a perfect ventilator, the air-column representing the initial vacuum H would theoretically be twice the head that corresponds with the circumferential speed of the fan. But the imperfections met with in practice require the insertion of a fractional coefficient B, less than unity, which the author calls the "manometric efficiency," to distinguish it from the fan's mechanical efficiency or useful effect proper. Putting therefore $H = K\frac{u^2}{g}$, the two foregoing formulæ become

$$h=\frac{Ku^2}{g\left(1+\frac{a^2}{b^2}\right)} \text{ and } V=\frac{0.65\,a\,u\sqrt{2K}}{\sqrt{1+\frac{a^2}{b^2}}}$$

For the usual English mode of stating the volume of the ventilating current in cubic feet per minute, and the vacuum in inches of water column, this ultimate expression for V holds good without alteration, provided the circumferential velocity u be taken in feet per minute and the areas a and b in square feet. But to get h in inches of water, while u is in feet per minute and g is 32.2 feet per second, a factor $\frac{12\times 0.0012}{60\times 60}=0.000004$ is required, assuming with the author that the density of air is 0.0012 if that of water is 1.0000; and the ultimate expression for the vacuum then becomes

$$\left.\begin{matrix}\text{Vacuum in}\\ \text{inches of}\\ \text{water-gauge}\end{matrix}\right\} = 0.000004\times\frac{K}{g\left(1+\frac{a^2}{b^2}\right)}\times\left(\begin{matrix}\text{circumferential velocity}\\ \text{in feet per minute}\end{matrix}\right)^2$$

Eliminating a, the two formulæ give $h=\frac{Ku^2}{g}-\frac{V^2}{2g\times(0.65b)^2}$; and writing M for the constant factor $\frac{1}{2g\times(0.65b)^2}$, the simple equation to a straight line is obtained, namely

$$h=H-MV^2$$

treating h as the ordinate, and the *square* of V as the abscissa. This equation presents the two-fold advantage, that it dispenses with the necessity for calculating the equivalent inlet orifice a, which represents the mine resistance to the pull of the ventilator; and that, by plotting graphically divers pairs of experimental values for h and V^2, it can be seen at a glance, and with great accuracy, to what extent these fall in with the straight line represented by the equation. On these accounts the author strongly recommends the adoption of this method for general use in observations or experiments on the working of ventilators.

Experimental Verification.—The validity of his theoretical conclusion was tested by the author by means of the data furnished from experiments made by the Gard Commission upon three ventilating fans in that district. For each of these, five different degrees of mine resistance were artificially presented to the pull of the fan, so as to cover the range of obstruction ordinarily encountered in mines having the smallest and the largest airways; the speed of the fan, the effective vacuum h produced, and the volume V of air-current, were measured. From these data was calculated the area b for the theoretically equivalent outlet orifice from the fan; and the ventilating current was reduced to correspond with an exactly uniform normal speed of 3,936 feet per minute for the circumference of each fan. The five pairs of values of h and V^2 were then plotted on a diagram; and the curve drawn through the five points so obtained was examined as to how nearly it was itself a straight line. The first ventilator, at Lalle colliery, Bessèges, was a kind of turbine of 12½ feet diameter, without casing, but working in a sort of semicircular wheel-pit, and discharging the air all round; its inlets were 6 feet diameter, and its width 4½ feet at center,

narrowing to only 2 feet at the circumference. The next, at Créal colliery of the Bessèges company, was 19¾ feet diameter and 3½ feet wide, with inlet 11½ feet diameter, in a casing with a short parallel chimney. The third, also at Bessèges, was a Guibal fan of 16½ feet diameter and 6½ feet width, with inlet 10 feet diameter, in a casing with adjustable shutter and expanding chimney, but without the latest improvement in the way of radial vanes.

With the Crèal fan running at 63⅔ revolutions per minute, the five results accorded most closely with the foregoing theory, falling into a straight line without appreciable deviation. Against the highest mine resistance, represented by the smallest equivalent orifice of only 6.604 square feet area, the air current was 17,928 cubic feet per minute, with an observed water-gauge of 1.060 inch, instead of the theoretical vacuum of 1.059 inch. Against the lowest mine resistance, corresponding with the largest equivalent orifice of 20.922 square feet area, the air-current was 50.357 cubic feet per minute, with an observed water-guage of 0.832 inch, instead of the theoretical vacuum of 0.834 inch. The greatest difference between the observed and the calculated water-gauge in the five experiments did not exceed 0.002 inch. Tabulating with these Crèal results the highest and lowest of those similarly obtained at Lalle and at Besseges, the comparison stands as follows:—

As the mine resistance scarcely ever exceeds that represented by so small an equivalent inlet orifice as only 4 square feet, while in large mines, even in England, it rarely falls below what corresponds with the largest inlet here tried of nearly 30 feet square, these results clearly confirm the author's theory within the limits prevailing in practice. The exceptional deficiency of ¼ inch water-gauge in the vacuum observed with the Guibal fan at Bessèges, when working against the greatest resistance and producing the least current, is accounted for by the corresponding partial closing of the discharge orifice from the fan casing by the regulating shutter, whereby the circumferential friction of the outlet bears an increased proportion to its area, and the efficiency diminishes rapidly. Moreover the forward inclination of the blades at their inner ends, intended for cutting the entering air without a blow, suits only the normal current for which it is calculated; with a much lower current there is a rapid loss of effect and diminution of vacuum. With smaller currents too it becomes increasingly difficult to realize the pull due to the expanding area of passage between the fan-blades and along the chimney; indeed in mines with narrow air-ways the vacuum falls short of what would be inferred from that observed in larger mines, and is also very irregular, being found to fluctuate at short intervals. In the above experiments the actual discharge orifice

Ventilator.	Speed. Revolutions per minute.	Mine resistance. Area of equivalent inlet *a*	Air current. Volume per minute	Vacuum by water-gauge. Observed.	Calculated.	Greatest difference.
	Revolutions	Square feet.	Cubic feet.	Inch.	Inch.	Inch.
Lalle, 12.46 ft. diameter	100.52	4.045	10,739	1.031	1.023	0.014
		14.868	35,744	0.846	0.835	
Créal, 19.68 ft. diameter	63.66	6.604	17.928	1.060	1.059	0.002
		20.922	50,357	0.832	0.834	
Bessèges 16.40 ft. diameter	76.39	3.921	11,239	1.180	1.304	0.124
		29.345	73,506	0.899	0.906	

Circumferential speed 3,936 feet per minute.

from each of the two fans at Creal and Bessèges was in every instance adjusted to an area proportioned to the ventilating current.

The graphic method, of the foregoing equation to the straight line, gives the initial vacuum H corresponding with a closed inlet and no current; and thence the manometric efficiency represented by the coefficient K is known from the equation $H=K\frac{u^2}{g}$. By the same means is also ascertained the area of the equivalent outlet *b*, representing the obstruction encountered in the fan itself; which is no matter of theory, but depends chiefly on the width of the fan, the area for the passage of the current through it, and the size of its inlet. These several values for each of the same three fans are as follows:—

Ventilator	Lalle.	Crèal.	Bessèges.
Circumferential speed, feet per minute	3,936	3,936	3,936
Initial vacuum $H = K\frac{u^2}{g}$ when producing no current } water-gauge, inch	1.041	1.089	1.314
Manometric efficiency, represented by coefficient K	0.542	0.572	0.691
Fan resistance, area of equivalent outlet *b*, square feet	30.086	37.868	43.831

Comparative Manometric Efficiency.—In a comprehensive table the author has collected for comparison the data respecting the working of all the fans he could, to the number of fifty-six. But as it has generally been only the fan speed that has been varied in the experiments recorded, while rarely has any variation been tried in the mine resistance, it is impossible from data so incomplete to deduce the fan resistance and the true manometric efficiency K. To the latter, however, a rough approximation is arrived at by substituting the effective vacuum *h*, observed under the ordinary circumstances of working, in place of the theoretical initial vacuum H which would exist if there were no current. In the case of the three fans previously considered, the extent to which the approximate results thus arrived at fall short of the true is seen from the following comparison:—

	Lalle.	Créal.	Bessèges.
True manometric efficiency K	0.542	0.572	0.691
Approximate manometric efficiency	0.468	0.524	0.569

Whence it appears that in default of the true method, the approximation may be employed for obtaining a fair idea of the comparative efficiency with different fans. The expression for the approximate manometric efficiency is therefore

$$\frac{2982\times(\text{observed water-gauge in millimeters})}{(\text{revs. per min.}\times\text{fan diam. in meters})^2}$$

$$\text{or}\ \frac{815603\times(\text{observed water-gauge in ins.})}{(\text{revs. per min.}\times\text{fan diam. in feet})^2}$$

which is applied to the whole of the fifty-six fans tabulated for comparison. The general results so arrived at may be summarized as follows:

Eighteen fans without casing—by MM. Combes, Detoret, Guibal, and Lambert—give an average of only 0.327 approximate manometric efficiency, the lowest being 0.090 and the highest 0.496. Five fans with casing, but without chimney, range from 0.429 to 0.682, the average being 0.560; but in one of these instances, where the same fan had previously been without the casing, its addition seems to have yielded no better result, and the author is at a loss to account for the anomaly. Four early Guibal fans, with casing and chimney, but the chimney parallel instead of expanding, range from 0.284 to 0.626; the average, even omitting two exceptionally low results, does not amount to more than 0.606, which suggests the question whether the chimney when parallel is really of any good, and whether the result is not due simply to the casing. With expanding chimney and regulating shutter, twenty-seven Guibal fans show an approximate manometric efficiency ranging from 0.545 to 0.751, excluding one exceptionally low result; the average is 0.650 In one of these instances—namely the Guibal fan of 23 feet diameter and 5½ feet width at Crachet and Picquery colliery, near Frameries, Belgium—where the result had been only 0.491 prior to the erection of the chimney, it was raised to 0.654 by the expanding chimney; while with an-

other Guibal fan of the same dimensions at Grand Buisson colliery, where the chimney had previously been parallel and was afterwards lined to the expanding form, the result was thereby raised from 0.626 up to 0.711. Two blowing fans of very good construction show results as high as 0.720 and 0.732.

Though larger dimensions of fan do not seem sensibly to augment its approximate manometric efficiency, yet the author suggests their great size as perhaps the cause of the high results presented by the three Guibal fans at Gethin colliery, Cyfarthfa, at Lwynypia colliery in the Rhondda valley, and at Pelton colliery, county Durham; these fans are each 30 feet diameter and 10 feet wide, and their approximate manometric efficiencies are respectively 0.661, 0.696, and 0.709, in spite of the very spacious airways through the workings they ventilate. On the other hand, the new Guibal fan of forty feet diameter and 8 feet width with radial blades, at Crachet and Picquery colliery, gives only 0.668, which though good is not so high as it would seem might have been expected; here however the object of so large a size was less to increase the efficiency than to get from a moderate speed of revolution a very high circumferential velocity, on which depends the actual vacuum that an exhausting fan can produce.

Since the volume of the air-current is what forms the ultimate practical aim in mine ventilation, and since this volume varies as the square root of the vacuum, the author points out that there is really but little scope left for further improvement upon the large exhausting fans now in use, which realize already an approximate manometric efficiency reaching 75 per cent. For even if their manometric efficiency could be brought up to the limit of theoretical perfection represented by 100 per cent., the corresponding increase in the ventilating current could not amount to more than 16 per cent. upon the current already obtained in practice.

Direct-Propelling Ventilators.—Distinguishing by this designation the various ventilators with helicoidal blades, like those of a screw-propeller or of a windmill, the author speaks of them as now fallen into disuse; he investigates their action, and shows that for the degree of vacuum and for the volume of the ventilating current the same formulæ which apply to centrifugal fans hold good here again also. The data respecting the working of fourteen mine ventilators of this class are tabulated for comparison; and their approximate manometric efficiency is found to be very low, the highest not exceeding 0.230. Besides being otherwise defective in construction, all more or less throttle the air in its passage through them. As with the fans, here also large diameters are conducive to efficiency. Though evidently so inadequate for mines, these ventilators answer well for the far easier ventilation of large halls; a pair of them employed in conjunction at the Trocadéro palace, Paris, produced together a current of 118,660 cubic feet per minute, with no higher pressure than 0.236 inch water-gauge, of which each singly gave only half; the area of the equivalent orifice representing the resistance encountered by the current in the building would thus be nearly 100 square feet. With improvements in construction to increase its efficiency, the author thinks a direct-propelling ventilator might in some cases be advantageously employed underground for opening out colliery dip-workings, where the air-current is often very weak; it would occupy but little room at the pit bottom, and the water falling into the sump could be utilized to drive a turbine fixed on the ventilator axle.

Mechanical Efficiency of Centrifugal Ventilators.—The useful work U done by any ventilator is simply the product of the effective vacuum h multiplied by the effective volume V of the air-current; or $U = h \times V$. Bearing in mind that, although the effective vacuum h falls short of the theoretical initial vacuum H which the fan would create if there were no current, yet the deficiency is due solely to friction and eddies in the passage of the air-current through the fan itself, it is clear that, however great its imperfections, the fan is really doing the larger work corresponding with the higher vacuum H, out of which only the portion h is useful or effective. Hence the expression for the driving power P, required on the fan shaft, will be $P = H \times V + L$, where L is the loss due to friction of bearings and to friction of the air against the ventilator casing;

the latter friction is ascertained by measuring the extent of stationary surfaces passed over by the current, calculating the mean velocity of the current rubbing against those surfaces, and employing an experimental coefficient of friction, the value of which, according to D'Aubuisson, would be 0.0032. Taking care to express L in the same terms as P, and to adopt the same unit of time for both of these as for V, the French and English formulæ become

$$\left\{\begin{array}{l}\text{Driving power P}\\ \text{in kilogrammeters}\end{array}\right\} = \left\{\begin{array}{l}\text{initial vacuum H}\\ \text{in millimeters}\\ \text{of water-gauge}\end{array}\right\} \times \left\{\begin{array}{l}\text{air-current V}\\ \text{in cubic meters}\end{array}\right\} + \left\{\begin{array}{l}\text{loss L}\\ \text{in kgm.}\end{array}\right\}$$

$$\left\{\begin{array}{l}\text{Driving power P}\\ \text{in foot-pounds.}\end{array}\right\} = 5.2 \times \left\{\begin{array}{l}\text{initial vacuum}\\ \text{H in inches}\end{array}\right\} \times \left\{\begin{array}{l}\text{air current V}\\ \text{in cubic feet}\end{array}\right\} + \left\{\begin{array}{l}\text{loss L}\\ \text{in ft.-lbs.}\end{array}\right\}$$

The useful effect E or mechanical efficiency of the ventilator will therefore be represented by the ratio of the useful work U to the driving power P; or

$$E = \frac{U}{P} = \frac{hV}{HV + L}$$

Since the air-current V varies directly with the speed of the ventilator, while the initial vacuum H varies as its square, it is seen that the principal term HV, in the expression for the driving power, varies as the cube of the speed; whence it is not so easy as it seems beforehand for the speed of a centrifugal ventilator to be varied to any large extent. Moreover, if the speed of running be maintained constant, the initial vacuum H becomes constant also; and then the power depends almost wholly on the amount of the ventilating current V. Hence arises the seeming paradox, that, if the mine resistance be augmented, less power is required and the fan speed quickens; whereas if the current have freer access to the ventilator, more power is needed and the speed slackens. Again, since the frictional loss L varies much less rapidly than as the cube of the speed, it follows that the useful effect improves as the speed rises; and this conclusion is borne out by all experiments in which different speeds of ventilator have been tried. Another inference from the much lower rate at which the loss varies with the speed is that with increase of speed the useful effect will rise to a maximum; and will afterwards fall off again, owing to the increasing friction of the current through the fan, and the consequently slower increase of the effective vacuum h than of the initial vacuum H. This is very clearly brought out in the experiments made by the Gard Commission, and shows that for every centrifugal ventilator there is a certain mine resistance which corresponds with a maximum of useful effect.

As a mine ventilator is generally driven by an engine working direct on its shaft, it but rarely happens that the driving power can be measured by a friction brake; an indicator on the steam cylinder is most commonly employed, and the loss L in the foregoing expressions then includes the engine friction, thereby causing the useful effect of the ventilator to appear lower than it really is.

Tabulating the lowest and highest results obtained from a number of different mine ventilators, with which repeated experiments have been tried under varied conditions of speed and mine resistance, the author collects the following percentages of useful effect:—

Kind of ventilator.	Perct. of useful effect.		
	Lo'est	Hig'st	Mean.
Two direct-propelling ventilators	22.0	32.4	26.0
Five centrifugal ventilators without casing (including that at Lalle)	16.0	47.0	27.8
Two fans with casing but without chimney	17.0	39.0	28.4
Three fans with casing and parallel chimney (including that at Créal)	32.0	51.7	37.9
Twelve Guibal fans with shutter and expanding chimney (includ'g that at Bessèges)	23.0	74.9	46.7
Three blowing fans	11.0	64.6	31.0

In the Gard Commission's experiments, included among the above, the useful effect ranged from 27.7 to 47.0 per cent. at Lalle, from 42.2 to 51.7 per cent. at Créal, and from 25.0 to 49.4 per cent. with the Guibal fan at Bessèges. The results in the first and sixth lines are the true percentages, free of engine friction; those in the four intervening lines all include the engine, and thus fall somewhat short of the fan's true useful effect. The

experiments on the twelve Guibal fans were sixty-five in number; and as the lowest percentages were here obtained from trials made under exceptional and very unfavorable conditions, the author considers that 50 per cent. may safely be taken as representing for ordinary working the mean useful effect of fan and engine combined. With the 23 foot Guibal fan at Crachet and Picquery colliery the useful effect ranged from 16 to 22 per cent. without the casing; from 17 to 31 per cent. when the casing had been added, but without shutter or expanding chimney; and after these had also been added, it ranged from 30.7 up to 74.9 per cent. in fourteen experiments made under great variations of mine resistance. The fellow Guibal fan at Grand Buisson colliery gave a useful effect of from 32 to 33.4 per cent. with its originally parallel chimney; and afterwards, with expanding chimney, the range was from 42.6 up to 72.5 per cent.

Practical Conclusions.—Theory and practice concur, the author considers, in pointing to the Guibal centrifugal fan as the best exhausting ventilator. Its approximate manometric efficiency has been found to average 65 per cent. of perfection. Assuming this coefficient, from the effective vacuum desired is then deduced the proper speed for the tips of the fan blades, which constitutes the main datum for the construction of an exhausting ventilator. Whether this speed shall be obtained by a small quick fan, or by a larger and slower, is left free to be decided by considerations of room, cost, and mechanical simplicity; only guarding against any risk of the fan presenting too small an area of passage through itself for the current necessary in a large mine. As to the number of fan blades, the author believes there is every advantage in having them numerous, because the air is thereby better guided, while the strain on the blades and their tremor are less; the only limitation is that their aggregate thickness should not be so considerable as to throttle the passage of the air-current through the fan. For the power necessary to drive the fan, it will be safe enough simply to reckon this at double the useful work required to be performed in the ventilation of any mine, since the useful effect of the Guibal fan has been found to average about 50 per cent.

In appended notes the author amplifies certain portions of his theoretical investigations, and substantiates certain of the data he has employed. He also compiles a table of values ranging between 1 inch and $1\frac{3}{8}$ inch water gauge for the theoretical initial vacuum which would be produced by a perfect fan running at any circumferential speed between the practical limits of 3,000 and 7,000 feet per minute.

THE LOAD-LINE FOR SHIPS.

"The Nautical Magazine."

Connected with merchant shipping, there probably never was a subject, having a greater degree of interest to all concerned in that great national industry, than the complicated and vexed question of freeboard—that point or mark upon the side of a ship to which she may be safely submerged, and beyond which it is avowedly dangerous to trespass.

It is, perhaps, one of the few things about a ship—even if all ships were alike in model—which cannot be determined by high scientific calculations; not, certainly, till such methods can further inform us on certain obscure points connected with wind and water; as, for example—first, how long and how *strong* a gale may blow, continuously, from *one* quarter of the compass; and, secondly, what elevation ocean waves may gather under such conditions, how fast they follow, and how abrupt their hollow and curling crests. Even with all such necessary information, probably not the wisest or most eminent of mathematical *savans* could, with all his learned figuring, advance us one little point beyond our present knowledge of the subject.

This present knowledge is said to be small, it is likely to continue so, if further explorations are to be conducted in the

mazy labyrinths of intricate calculations, as to the various altitudes and volume of wave crests, as, when driven by the storm, they sweep on the decks of deep or moderately loaded ships.

There is one important element in this still more important matter, which in the somewhat over-refined investigations hitherto conducted, has been a little, if not altogether, overlooked, and that is the condition and strength of the decks and their various openings and fittings; for it may be laid down as a most certain, self-evident fact, that if the decks are not thoroughly secure, the most liberal allowance of freeboard is thrown away. But little acquaintance with ships in their character of floating bodies is necessary to recognize the assurance that with but half an inch of "freeboard" a vessel will securely float, and continue to do so as long as her hull or her decks are strong enough to resist the battering effect of heavy seas—just as long, in fact, as she is secure against the invasion of water or other additional weight. There is one thing that we know, or should have learnt from the vast experience of the last ten or twenty years—an experience perhaps as gloomy and unsatisfactory as it has been rash—that the majority of "cargo steamers," as at present constructed and sent to sea, have already, long since, reached the limit of safety in loading, if, indeed, many of them have not got much beyond it. If this be not so, how are we to account for the great number of such vessels which annually disappear? There is, surely, unmistakable evidence to prove that something is wrong *somewhere*, for many of them are comparatively new ships. After two long centuries of experience of all kinds of ships, and over all seas, a vanished school of able and sagacious seamen laid it down that a good ship, fairly loaded and ably commanded, will live in any storm, excepting, perhaps, cyclones and hurricanes, and the accidents which they engender; she positively cannot sink, but is as certain to ride over these great rolling mountains of seething water as a well built church is of standing on its foundation.

This does not, however, apply to the all present generation of iron steamers; it had reference, especially, to first-class wooden ships, such as were the glory and pride of England some fifty years ago; ships which invariably carried high and bold sides. The experiences, however, of the present age of seamen, respecting many of the ships which now convey our commerce would lead nearly to the same happy conclusions. Take, for example the steamships of the great companies which traverse the wild and stormy Atlantic, than which there is no ocean more tempestuous, and we find that over a long period of years there has been, as far as we actually know, no loss from this cause —of foundering. A company, whose ships are as far above suspicion as was Cæsar's wife, can apparently truthfully declare that during upwards of forty years exposure on this ocean they have never lost the life of a single passenger by a case of foundering. So much for large first-class passenger steamers. Now, on turning to small sailing ships, what state of things do we find there? We are told by captains of yachts, decked fishermen, pilot boats, even many open boats, and also by the officers of small trading vessels, ranging from 100 to 300 tons, that when "staunch and strong" as they should be, and *fairly* loaded, they consider them even safer than big ships, and vastly drier, in a seaway.

It is also, we know, a common thing for open boats, heavily loaded with their crews, to live in a sea which has swallowed up the parent ship. It is further on record that Cook, on being given his choice of a ship for his voyage in quest of an Antarctic continent, put his hand on a small brig as being, in his opinion, *most capable* of wrestling with the howling storms of an untraversed and remote sea. Bearing all this in mind, there are only, mainly, about two conclusions to be come to respecting the enormous number of ships which now founder in the open sea or are missing. The first is, that from various causes, they are not seaworthy in point of construction; and, the second, that if seaworthy in this respect, they are overloaded. There are few men who understand what a ship is capable of doing who would care to assure her safety during a winter passage with but 18 per cent. of buoyancy. Not that this amount is in all cases too little, but for such extreme submergence there should be special models of ships, and special methods of deck formation and

construction with more length and greater submersion. There *must be* reform of model above board, and greater strength. This is as "certain as mathematics."

A cask of wine, with its top just awash, will float through many heavy gales and yet preserve its contents in good order; and any ship would do the same, if *strong enough*; thus it would appear that the solution of this matter is to be sought for as much in increased strength and security of decks, as in any other direction. There must, however, be no mistake made as to the *degree* of strength; for, to make a steamer of 1,000 tons as strong, proportionately, as a well-coopered, level wood cask—in such a situation—and to render her decks as free from obstructions, would simply be to make her next to useless as a freight earning machine. She must first, at all events, have a funnel, with its accompanying uptakes, ventilators, &c., and something in the shape of a bridge, and more or less of a deck, with hatchways and other indispensible fittings.

It would also be discovered by those who made the trial, that to submerge her further than 82 per cent. of her midship volume, notwithstanding the *many questionable* advantages of great sheer, would render a complete and radical change necessary, in the planning and fitting of her decks. A case has already been cited in this journal of a new steamer, on her first voyage, falling off into the trough of the sea and having her hatchways completely knocked in by the first sea which fell aboard, causing the immediate loss of that ship by foundering, the probable fate of great numbers which disappear.

Five and twenty years ago when ships, by having less length and greater freeboard, were far more bouyant than at present, it was a common spectacle, during a gale and heavy sea, to see substantial deck fittings brushed away like loose dust; and on board of ships which had been carefully loaded in accordance with Lloyd's rules. Piling timber on timber, and bolt upon bolt, is but labor in vain in the shape of hatchways and houses. Hardly anything in the guise of wood in low-sided ships can stand the breaking charge of a heavy sea when once getting above the hatchways. *Iron* might even be included in this category, when it is remembered that the substantial metal attachment of a heavy bell on the top of the Bishop Rock Lighthouse, 110 feet above high water springs, was broken off short by a "spray" from a S.W. sea, and even but a month ago, one of the great mail steamers, during a moderate gale, had her reefed mizen swept entirely away by a sea which fell right into the belly of the sail; the *boom* of this mizen was just 20 feet above the load-line.

Such, indeed, are old stories, but, nevertheless, true ones; they may serve, perhaps, to impress upon incredulous and virgin minds the fact that ships should be constructed to ride *over* the waves instead of through them. If we are going to sail our ships *under* the waves, we may begin as soon as we please to smooth them off on deck like the bilge of a wine-cask, that is to say, if we want them to come home again. The vessels already mentioned represented the marine of this country in its transition state, from the stately old castles of the East India Company to the present iron cargo steamers; such ships when running before a gale and a true long rolling sea, would occasionally ship from 150 to 200 tons of water, which would come rolling in on each side as the crest of the wave swept by. Having from five to six feet of freeboard, and about five feet of bulwark above it, and although such buoyant fabrics compared with the present, they frequently found themselves in great jeopardy, and such a thing as a main-hatch giving way was not unknown.

It is a great mistake to suppose, as some ship-builders really do, that because a ship is *big* no heavy seas will ever run on board; in consequence of this fallacy they take all manner of liberties in designs and construction. It is difficult to believe there are such opinions in such quarters; yet it is so, notwithstanding. There is doubtless, less science imported into shipbuilding now than in former times, when iron for such work was a novelty, and when the worthy blacksmith, though occupying an indisputable position, played only second fiddle in the symphony; but the merest riveter should understand that the long, *low* steamers which are now turned out of our building yards are the wettest, and

in too many cases the most dangerous ships which ever put to sea.

A great ocean wave, however high or fast it may run, will lift up, bodily, any small ship or boat, but not so some 400-footer; and, as a matter of course, if it cannot lift, must run over some part of her.

Allowing such a wave to run at 35 miles an hour, and a great part of its crest, say 25 tons of water, to overwhelm her decks, we have at once a force equal to the *charge of a locomotive* against everything in the shape of an obstruction to its course. Yet it is common to see such ships putting to sea with all kinds of trumpery and feeble fittings—such as obtained in high-sided ships of fifty years back—*feeble*, it should be said, in relation to the amount of freeboard, or bad weather to be encountered; and afterwards doleful accounts in the newspapers about "terrific weather, and fearful damage."

It is, perhaps, unnecessary to mention here how many large ships have lately foundered in home waters from such cause, and how their heavily loaded open boats have survived the ordeal which the parent was unequal to.

Respecting the great question of freeboard, it is highly probable that if a dozen of the most experienced and intelligent captains of, say, some of the Black Sea steamers, were about to insure one of their vessels against a winter passage, they would unanimously stipulate for the following conditions:

1st. That if about 300 feet long, she should have no less than 20 per cent. of buoyancy of midship volume, measured from the lower part of sheer of main deck, on leaving port.

2d. Moderate sheer, and camber of deck.

3d. To have poop and forecastle, and midship upper deck.

4th. The two former to be constructed more for throwing off heavy seas than for any other purpose; with windlass on main deck; extreme elevation of such constructions to be rather *under* than over the average, with great camber to their decks.

5th. Midship upper-deck to enclose engine and stoke-rooms, and all openings or passages thereto to extend from side to side of ship, with watertight door for passages, if desirable; and this upper-deck to have a length of from $\frac{1}{4}$ to $\frac{3}{10}$ of the extreme length of ship; to accommodate all or greater part of crew, and to be, in fact, for the most assailable and weakest part of the ship a fortress against water.

6th. Two feet of substantial iron bulwarks, with the same amount of guard rail above it.

7th. To have most substantial and approved deck-fittings, calculated to stand a strain of at least two tons to the square foot.

8th. Coamings of hatchways 30 inches high, and the hatches themselves fully as strong as the decks, with portable iron beams to support fore and after.

Such would, doubtless, be some of their most important requests.

No ship should have *any* allowance for midship deck erections, which did not embrace all the conditions of Art 5.

It is difficult to see why any allowance should be made for closed-in poop and forecastle, they *do* throw off end-on water, but not beam seas, which are the most dangerous. Indeed, nearly any steamer might be overwhelmed and broken up amidships, *before* the supposed buoyancy in such end constructions began to act; and until they *do* begin to act, that is to say, until the water reaches them, they do actually by their simple weight oppress her.

If, for example, she is thrown on her beam ends, or over to 45°, which is about the most usual angle, they all the time are bearing her further over, and when their buoyancy did begin to tell, supposing they are closed in, the ship would probably, with her engine room full, be beyond relief.

The engine room of such a ship would, in event of an accident, begin to fill when over at an angle of 20°, but the buoyancy confidently looked for in the end erections would not commence till she was over at an angle of about 80°, or just on the point of sinking. Even with an end-on sea, when the crest was about amidships, and attacking and breaking up this vital part, these heavy erections are in the trough, and all the time bearing her down, like the uplifted arms of a drowning man. The allowance made for great sheer puts the ship very low in the water, *in* this vital part, and which in the

battle has to stand the brunt of the attack. In driving hard, a bow that will readily throw off water is better than a necessarily high one—for one or two feet of extra height make no appreciable difference in a heavy head sea; but such vessels do not "drive hard," and what they want more than any other thing is some kind of certain security, or sanctuary, when lying to or when things come to their worst. In lying to under sail they are comparatively dry forward and aft and very wet amidships, and invariably weakest at this, their supreme point of stability and buoyancy. By having a moderate sheer the poop and forecastle do not so powerfully affect the stability in lurching or pressing. But the great object in all such vessels, indeed in long vessels of any kind, is to have perfect strength and security amidships, for during a heavy beam sea that part of the ship can neither rise nor give way so readily as the ends when charged from windward. On the lee side a very few degrees of "list" either as a heavy lurch or pressed over by canvas, quickly puts the low-moulded main-deck under water, when of course buoyancy in that part ceases, and the first process of sinking or capsizing actually begins.

The upper and *complete* midship deck is a safeguard against this very liable accident, or, more properly, natural evolution. And it is not only the grain steamers which shift their cargoes by their constant lurching, for cargoes of all kinds are now taken in so hurriedly that a succession of heavy lurches during a gale of wind will speedily give any ship a very undesirable list, simply by the constant sag-sagging of a moderately slackly stowed cargo. Under such conditions the coals in the bunkers will themselves contribute four or five degrees

But to return again to freeboard, perhaps the most certain and simple way of coming quickly to a practical conclusion is to do as the Admiralty did with their monitors. Have a steamer ready, of the usual make up and trim, with a party of commissioners—royal or otherwise—on board, and waiting in some convenient harbor for a gale of wind; then let her go to sea, and let the gentlemen have, then and there, ocular demonstration of her performance. By carefully selecting from many well-known specimens, some possible basis may be secured upon which to work out other calculations. But whatever conclusion is come to, it is fully time that a great and rich maritime nation put an end to such grievous and discreditable loses which are now nearly daily posted up. Independently of the destruction of national wealth and prestige, it is scandalous that the children of sailors shall be made orphans, and their wives widows, in order to save to the well-fed millions of this prosperous country a paltry halfpenny in the price of a loaf, or sixpence in the cost of a coat. For in the supposition that freights would soon find their normal level, such is almost the only gained advantage; and nobody would be more desirous of seeing ocean steamers made as secure as the machinery of other great and successful manufactures than the general mass of honorable shipowners of Great Britain.

It has already been intimated that a most successful body of shipowners, during forty years of trading, have never lost a ship by foundering; and the same thing is still going on—without Government assistance.

It is useles to talk about "handicapping" English ships, for few ships load so deep, run such risks, or pay so well as those under discussion. They are, in fact, the "leaders of fashion" in this matter.

The thing can be done as surely, and will *pay* as surely, as it pays one, out of many great manufacturers, to have tennis grounds for his young men or grand pianos for his young women; or on the other hand, as it pays a successful costermonger to have *weight-worthy* wheels to his cart. As a rule, the more secure, and safe and perfect that the machinery of all industries *becomes*, the more successful are the manufacturers.

If anybody doubts this, he must at least admit that the harvest wagon wheels of a great and rich nation must be made secure, and the lives of the wagoners as safe as human hands and heads can devise.

THERE is a regular telephonic service on some of the Austrian secondary railroads, so that all of the stations can communicate with each other.

ON THE ADHESIVE STRENGTH OF PORTLAND CEMENT WITH SPECIAL REFERENCE TO AN IMPROVED METHOD OF TESTING THAT MATERIAL.

By ISAAC JOHN MANN.

From Selected Papers of the Institution of Civil Engineers.

THIS communication refers principally to an investigation of the adhesive or cementitious strength of Portland cement, and a description of improved method of determining its quality and value, with a view to establish a simple and generally recognized standard system of testing.

The author believes that it may be fairly assumed that the principal function of cement is to produce adherence, so as to convert loose or disconnected material into a solid coherent form; and that it may be further assumed that the economy with which this object can be gained will, *cæteris paribus*, be in proportion to the adhesive strength of the cement employed.

Reviewing the history of cement-testing, and the experimental researches connected with it, the conclusion seems almost inevitable that neither of the systems at present in general use—one depending on the cohesive strength of neat cement, the other on that of a mixture of cement and sand—are likely to become universal.

The principal test adopted by the author is one of adhesion. It has been used by him for some years with very satisfactory results, and he believes it will be found to possess elements which recommend it strongly for general adoption. The mode of applying the test is extremely simple, involving neither skill nor experience on the part of the operator, and most, if not all the complications of details incident to other systems can be avoided. The simple and inexpensive testing machine designed by the author consists of a steel lever with a knife edge bearing on the fulcrum; the strain is applied by a thumb-screw, and registered by an accurate spring-balance, the dial of which is provided with a maximum index-hand; the samples are cruciform in shape, and consist each of two pieces of sawn limestone or ground plate-glass, $1\frac{1}{2}$ inch by 1 inch, by $\frac{1}{4}$ inch to $\frac{3}{8}$ inch. When a sample is to be broken, it is placed on two vertical supparts under the end of the short arm of the lever. An adapter, with a steel centerpoint fitting into a small conical recess at the end of the lever, enables the strain to be brought on the sample with great accuracy and facility, and a cushion of soft wood or india-rubber fixed in the adapter checks the recoil after fracture. The center-point can be provided with a screwed end, to permit adjustment in case the cement joint should inadvertently be made thicker than necessary: this, however, is an unlikely contingency. Limestone or ground plate-glass are suitable for standard tests; the former because it is readily obtainable, of sufficiently uniform texture, and enters largely into construction; the latter on account of its being homogeneous and easy to obtain.

The cement to be tested is gauged to a suitable consistency, and applied with a spatula to one of the test-pieces; the other being placed in position, a slight pressure is sufficient to squeeze out the superfluous cement, which forms a fillet tending to protect the extreme edges of the joint from any "wash" that might occur in the act of immersing the sample, or at any time previous to setting, and which can be removed after the cement has set. When the samples are made they are numbered, and at once placed in water in shallow vessels, which are also numbered, or lettered, to facilitate identification. After fracture the remaining cement is removed from the test-pieces, which can be used as often as required.

The transition from the German or mortar test to one of adhesion is not so abrupt as would appear: in the former a great number of small pieces of stone are used, in the form of sand; in the

latter two pieces only are employed, and the test is thus simplified and better defined. The German test, however, is neither one of cohesion only nor of adhesion, but involves an indeterminate proportion of each, which cannot be considered desirable.

In his investigations of the cementitious or adhesive strength of cement, the author was necessarily obliged to devote considerable attention to the influence of the coarse particles. The test of adhesion alone, even without any qualification as to grinding, would be almost sufficient to determine the practical value of cement, the weakening effect of the coarse particles becoming at once apparent, as will be seen from the following tests:—

TABLE I.—EFFECT OF COARSE PARTICLES ON THE CEMENTITIOUS OR ADHESIVE STRENGTH. Age of samples, twenty-eight days.

Percentage of coarse particles	0 fine only	20	40	80	100 coarse only
Average adhesive strength in lbs. per square inch.	101	84	57	34	18

Percentage of coarse in the unsifted cement, 49. Cohesive strength of the same after seven days, 430 lbs. per square inch. Number of tests, twenty. Test-pieces, sawn limestone.

The coarse particles referred to above were those stopped by a silk sieve of 176 meshes to the lineal inch, the meshes being about 0.004 inch by 0.004 inch; a sieve of such fineness, although not heretofore used in ordinary testing, has been found to afford more definite and reliable results than those having larger meshes.

Another series of tests gave the following results after seven days' immersion; the same sieve being used to produce the required degree of coarseness:—

Fine cement only	91	lbs. per sq. in.
25 per cent. of coarse particles.	63	" "
75 " " "	26	" "
Coarse particles only	8	" "

Cohesive strength of the cement as supplied, 532 lbs. per square inch. Age, seven days.

Although these, and numerous other tests of a similar character, have been sufficiently satisfactory and conclusive, the presence of coarse particles may be regarded as introducing an element which might possibly help to interfere with perfect uniformity in results, and which might therefore with advantage be eliminated in a standard test; a simple and obvious alternate will be found sufficient to overcome the objection referred to.

It can hardly be doubted that the strength of a joint made with ordinary cement must be influenced by the fortuitous position which the coarse particles occupy; or, in other words, by the proportion of inert, or comparatively inert particles which happen to be in direct contact with the cemented surfaces. In accordance with this view, the author proposes that one of the standard adhesive tests should be applied after the inert particles have been removed by sifting through a standard sieve.

Cement, as at present received from the manufacturer, so far as concerns the cementitious strength capable of being developed in the period to which ordinary testing must of necessity be limited in practice, consists of a mixture of active, and inert, or extremely sluggish material, and the latter may be considered almost as foreign to the true cementitious portion, as so much sand.

This view is supported by the following experiment: The coarse particles stopped by a No. 176 sieve, amounting to 49 per cent. of the cement as supplied, were removed, and sand of approximately the same granulation substituted; the average adhesive strength of this compound or mortar, compared with that of the ordinary cement after seven days' immersion, was—

Sand and fine cement.. 49 lbs per square inch.
Ordinary cement..... 56 " "

Test-pieces, sawn limestone.

Separation of the inert and active portions would be manifestly desirable, as forming, in combination with an adhesive test of the latter, a simple means of arriving at a true estimate of both the cementitious and commercial value of any given cement, in much the same way as the value of an ore is estimated by the percentage of metal it contains. The author's attention was therefore directed to this part of the subject, with a view to discover, if possible, the degree of pulverization required to convert the

underground clinker into active cement, capable of developing its cementitious properties within the period allowed in practice for testing purposes.

Some of the principal results of the experiments, up to the present time, are contained in the following table; unfortunately others applying to lengthened periods had to be discarded, owing to accidental exposure to frost, which in many cases seemed almost to destroy the adhesive strength. In several instances the coarse particles were rapidly washed in two or three waters, to remove a minute quantity of fine cement which adhered to them after sifting. The No. 176 sieve, used to separate the coarse particles, was the finest that could be obtained, arresting from 38 to 50 per cent. of the ordinary cement. No. 103 sieve retained from 25 to 30 per cent.; the unsifted cements required from forty minutes to five hours to set in air, the temperature of which varied from 50° to 70° Fahrenheit. They were obtained from well-known manufacturers, and had an average cohesive strength, after seven days, of 425 lbs. per square inch, their average adhesive strength being 61 lbs. per square inch, and 84 lbs. per square inch after seven and twenty-eight days' immersion respectively.

A set of samples eleven months old, made from cement passing a No. 54 sieve and stopped by a No. 103 sieve, but not washed, and having therefore a minute quantity of very fine cement adhering, showed an average adhesive strength of 21 lbs. per square inch.

The figures given in the table are in some cases the average of six tests, but in general that of three. In these, as in all the other experiments on the adhesive strength recorded in this paper, the test-pieces, unless otherwise stated, were of sawn close-grained limestone, and were placed in fresh water immediately after being cemented together.

The above examples, although far from exhaustive, lead to the following conclusions:—

1. That so far as concerns a seven-days' test, the particles of cement stopped by a No. 176 sieve developed little or no cementing power during that period, and that even some of the less fine particles passing the sieve may be very deficient in cementitious strength.

TABLE II.—ADHESIVE STRENGTH OF THE COARSE PARTICLES of PORTLAND CEMENT.

Age.	Average Strength in lbs. per sq in.	Degree of Pulverization.
7 days	1	Stopped by No. 176 sieve and washed.
7 "	0	54 per cent. of fine particles removed by washing only.
7 "	6	Fine removed by No. 176 sieve; very coarse by No. 54 sieve.
8 "	8	Particles which passed No. 176 sieve, after very fine had been removed by ten minutes' sifting.
8 "	0	Stopped by No. 176 sieve and washed.
8 "	6	Fine removed by No. 158 sieve; very coarse by No. 54 sieve.
9 "	0	Stopped by No. 103 sieve.
9 "	½	Stopped by No. 176 sieve and washed.
28 "	12	Particles which passed No. 176 sieve, after 46 per cent. of fine had been sifted out.
28 "	14	Fine removed by No. 176 sieve; very coarse by No. 54 sieve.
28 "	5	Stopped by No. 176 sieve.
28 "	18	" " "
28 "	20	Fine removed by No. 176 sieve; coarse by No. 103 sieve.
28 "	1	Fine removed by No. 103 sieve; very coarse by No. 54 sieve, and washed.
28 "	9	Stopped by No. 176 sieve and washed.
28 "	14	Fine removed by No. 158 sieve; very coarse by No. 54 sieve.
28 "	18	Fine removed by No. 176 sieve; very coarse by No. 54 sieve, and washed.
28 "	0	Fine removed by No. 176 sieve; coarse by No. 103 sieve.
28 "	2	" "
28 "	3½	Stopped by No. 176 sieve and washed.
28 "	24	Passed No. 176 sieve, after very fine had been removed by sifting for two minutes.
15 weeks	20	Fine removed by No. 176 sieve; very coarse by No. 54 sieve.
15 "	14	Stopped by No. 176 sieve and washed.

Number of tests, eighty. Test-pieces, sawn limestone.

This was further shown to be the case by the following tests: A weight of about

300 or 400 grains of ordinary cement was placed in the seive (No. 176); after sifting gently for thirty seconds, a quantity of the very finest passed through, which was made into samples, the cement passing through the sieve during the following two minutes was rejected, the sifting being continued until sufficient cement to make four samples had passed, leaving, however, a large portion still in the sieve. The adhesive strength of the former samples was much greater than that of the latter when tested after seven days' immersion. This was repeated, using the cement of other manufacturers, with the same result.

2. That so far as concerns a twenty-eight days' test, the cement of different manufacturers varied in the cementitious strength of the particles stopped by No. 176 sieve, from nothing to 20 lbs. per square inch, their strength increasing but slowly in the longer periods, and probably becoming soon exhausted.

No. 176 and No. 103 sieves were of silk, the meshes being respectively about 0.0040 inch and 0.0075 inch square, and slightly smaller than those of the same numbers formed of wire. The author has since, through the courtesy of Dr. Michaelis, of Berlin, been furnished with a woven brass wire sieve, of almost the same fineness as No. 176 silk sieve. The time required to sift 400 grains weight, using a sieve about 4 inches in diameter, varied from fifteen to twenty minutes, the operation being facilitated by the addition of a few small round pebbles.

If any general conclusion can be drawn from the table, which represents only eighty tests, it would appear to be that the cementing energy of coarse particles develops much more slowly than that of the fine particles. The necessity of adopting a high standard of pulverization is also shown. For example, the particles which were sufficiently fine to pass a sieve of ten thousand six hundred meshes to the square inch, viz. No. 103, possessed less than one-fifth of the cementitious value of those passing a sieve of thirty-one thousand meshes per square inch, viz. No. 176.

The adoption of a high standard of pulverization need cause no apprehension to manufacturers, as the percentage of cement stopped by a standard sieve, and the price, can be mutually accommodated to meet all the commercial exigencies of the case.

The degree of pulverization of the cement supplied by some of the principal manufacturers fluctuates between comparatively narrow limits, as may be seen from the following table:—

TABLE III.

Maker.	Percentage by weight stopped by a No. 176 sieve	Maker.	Percentage by weight stopped by a No. 176 sieve
F	49	L	49
D	47	S (quick setting)	41
G	45		
G	46	S (slow setting)	47
H	43	Y	38
I	47		
K	50	General average	.. 45.6

A slight modification only is required to adapt ordinary specifications of cement to the terms proposed by the author.

The next point requiring investigation is the adhesive or cementitious strength of the fine particles. For this purpose the finest sieve obtainable, viz. No. 176, was used, and the cement sifted until an inappreciable amount escaped through the meshes.

In the two following tables will be found some of the principal results ob-

TABLE IV.—ADHESIVE STRENGTH of FINE CEMENT SIFTED THROUGH No. 176 SIEVE. Age, seven days. Test-pieces, sawn limestone.

Manufacturer ..	A	B	B	C	D	D	E	B	C
Cementitious strength in lbs. per square inch	61	101	101	69	73	91	85	100	84

Manufacturer ..	A	F	G	A	H	I	K	F	G
Cementitious strength in lbs. per square inch	70	57	65	74	63	83	66	81	82

Number of tests, sixty-two. General average, 78 lbs. per square inch.

TABLE V.—ADHESIVE STRENGTH of FINE CEMENT SIFTED THROUGH No. 176 SIEVE. Age, twenty-eight days. Test-pieces sawn limestone.

Manufacturer.	H	C	D	I	B	H	F	L	L	K
Cementitious strength in lbs. per sq. in.	71	121	66	84	110	100	77	88	109	105

Number of tests, thirty-eight. General average, 93 lbs. per square inch.

tained from cements of ten different manufacturers, requiring from forty minutes to five hours to set in air. Extremely quick and very slow-setting cements were reserved for Table XII.

Considerable differences are apparent, not only in the cements of different manufacturers, but also in different cargoes from the same maker, and occasionally in the same cargo. Most of the tests relating to longer periods were unreliable from exposure of the samples to frost; a limited number, which escaped exposure to frost, had an average adhesive strength of 116 lbs. per square inch after thirteen weeks' immersion, while others of a different manufacturer, which had been in water for six months, had a strength of 113 lbs. per square inch. A set of samples, which had been some months immersed before being frozen, and therefore better able to resist injury from this cause, had an average cementitious strength, after fifteen months, of 173 lbs. per square inch, one of the samples exhibiting the highest development of adhesive strength which the author has yet observed, namely, 240 lbs. per square inch. The weight of fine cement from which this cementitious energy was developed did not exceed 5 grains. This strength is equivalent to nearly 16 tons per square foot; but few, if any, masonry-joints are ever subjected to a tearing strain of this severity.

Owing to the author preferring to make all the tests himself, and to the limited time at his disposal, the averages represented by each of the figures in the tables have been derived from three to six tests. In ordinary testing, however, it would be desirable to take the averages from not less than six tests.

Although the test proposed to be applied, after removing the inert particles by an extremely fine sieve, will probably give the most trustworthy and uniform results, the adhesive test should be also applied to the cement as received from the contractor, and as actually used in construction, this test alone being almost sufficient to enable a correct estimate to be formed of the value of the cement.

In the following tests of the cementitious strength of ordinary cement the extremes of quick and slow setting were avoided. In every case, unless otherwise stated, the cement was immersed in fresh water immediately after the test-pieces were joined:—

TABLE VI.—ADHESIVE STRENGTH OF ORDINARY CEMENT AS RECEIVED FROM THE MANUFACTURER. Age, seven days. Test-pieces, sawn limestone.

Manufacturer.	G	K	I	F	F_1	G_1	G_2	H
Cementitious strength in lbs. per sq. in.	76	57	51	69	71	73	59	56

Manufacturer.	G_3	W	F_2	W_1	W_2	G	F_3	K_2
Cementitious strength in lbs. per sq. in.	52	50	54	59	41	37	51	56

Number of tests, sixty. General average, 57 lbs. per square inch.

The cements of well-known makers were used, and with one or two exceptions the results are tolerably uniform, considering that nearly 50 per cent. of the material tested was practically inert, and its position relative to the surfaces of the test-pieces uncertain. The highest and lowest figures in the table were obtained from the same cement; it was however the slowest in setting, and nearly twelve months elapsed between the two tests. The test-pieces should in every case be scrupulously clean, and allowed to remain in water for a short time before using.

Table VII. shows some of the principal results obtained from a twenty-eight-day test of ordinary cement.

TABLE VII.—ADHESIVE STRENGTH OF ORDINARY CEMENT AS RECEIVED FROM THE MANUFACTURER. Age, twenty-eight days. Test-pieces, sawn limestone.

Manufacturer.	H	H_2	K	K_1	F	F_1	W	W_2	G	G_1
Cementitious strength in lbs. per sq. in.	78	57	48	71	98	69	91	84	108	75

Number of tests, thirty-six. General average, 78 lbs. per square inch.

Estimated by their cohesive strength the cements were all of good quality. The differences are not so great as those in the preceding table, and no doubt can be partly accounted for in the same way. Of course the cements of different makers could not be expected to show perfectly uniform results, but the averages would probably be only slightly altered if obtained from a larger number of tests.

Table VIII. shows the results of a limited number of tests after thirteen weeks' immersion of the samples.

TABLE VIII.—ADHESIVE STRENGTH OF ORDINARY CEMENT, AS RECEIVED FROM THE MANUFACTURER. Age of samples, thirteen weeks.

Average strength in lbs. per square inch.	Remarks.
110	Test-pieces, sawn limestone. Samples made with and immersed in sea-water.
113	Test-pieces, ground plate glass. Fresh water.
60	Test-pieces, sawn limestone. Fresh water.
110	Test-pieces, sawn limestone. Fresh water.

Average 98 lbs. per square inch.

A series of samples which had been immersed for seven months had an average strength of 128 lbs. per square inch. Another set which had been frozen, had a strength after twelve months of only 40 lbs. per square inch, while some samples of the same cement, but with the coarse particles removed by a No. 176 sieve, although similarly frozen and of the same age, had an average strength of 107 lbs. per square inch. The comparative cementitious strength of the sifted and unsifted cements tested by the author is given in Table IX.:—

TABLE IX.

COMPARATIVE CEMENTITIOUS STRENGTH OF SIFTED AND UNSIFTED CEMENT.

Description.	Averages in lbs. per sq. inch.		
	Age, seven days.	Age, twenty-eight days.	Age, thirteen weeks.
Cement with the coarse particles removed by No. 176 sieve.....	78	93	116
Ordinary cement as received from the manufacturer.....	57	78	98

These results are satisfactory, particularly with reference to their bearing on the subject of the deposition of concrete or rubble-in-concrete, in deep water, a method of construction which can be applied with such economy and rapidity of execution as to supersede the slow and costly methods which involve the use of cofferdams or large blocks. The adhesive strength shown by the author's experiments indicates the great stability and monolithic character of structures in which Portland cement is employed as the cementing material, and immersed before setting. In several instances when the test-pieces consisted of comparatively soft but otherwise sound stone, such as Portland and sandstone, the adhesive strength of the cement was sufficient to tear small fragments out of the surfaces of the test-pieces, the age of the samples being only twenty-eight days, and the breaking-strain slightly below the average of ordinary unsifted cement (Table XV.).

In drawing any inference from Table IX. it should not be forgotten that to produce the strength shown in the second line of figures involved the use of, at least, four times the quantity of cementing material required to produce the superior strength shown by the figures in the first line, or those referring to the sifted cement, owing to the difference in the thickness of joint caused by the presence of the coarser particles. The averages given above are derived from tests applied at various times to the cements of twelve different makers. An abstract of some of the principal tests applied to the same cement, or that made by one of the manufacturers, is given in Table X. (page 239).

The relation, if any, between the cohesive and adhesive, or cementitious strength of neat cement seems to be extremely obscure, as might be anticipated from the fact that the presence of coarse particles within certain limits increases the former but diminishes the latter. The following examples will serve to show that the ordinary seven-days' test of tensile or cohesive strength is unreliable as an exponent of the cementitious value. (Table XI., page 239).

The author believes that the cohesive test has not unfrequently led to the rejection or condemnation of excellent cement. For example, in experiment No. 9, Table XI., the low tensile strength of the cement would probably have caused

TABLE X.—ABSTRACTS OF PRINCIPAL TESTS APPLIED TO THE SAME CEMENT. Test-pieces, sawn limestone.

Age.	Average adhesive strength in lbs. per square inch.	Remarks.
1 day...	15	Ordinary cement.
3 days..	36	" "
7 " ..	76	" "
7 " ..	73	" " 2d set of samples.
7 " ..	91	Fine only, separated with No. 176 sieve.
7 " ..	63	Fine, with 25 per cent. of coarse added.
7 " ..	26	Fine, with 75 per cent. of coarse added.
7 " ..	8	The coarsest particles that passed through No. 176 sieve.
7 " ..	0	Stopped by No. 176 sieve
28 " ..	1	" " " another set of samples
28 " ..	88	Ordinary cement.
28 " ..	84	" " gauged with and immersed in sea-water.
" ..	120	Ordin'ry cement gauged with and exposed to air and sea-water each alternate day.
15 weeks.	20	Fine, removed by No. 176 sieve, very coarse by No. 54 sieve.
15 " ..	14	Stopped by No. 176 sieve and washed.

Average strength of cohesion of the ordinary cement is supplied after seven days, 480 lbs. per square inch. Pulverization, 45 per cent. of the ordinary cement stopped by No. 176 sieve.

TABLE XI.—COMPARISON OF ADHESIVE AND COHESIVE STRENGTH.

No.	Description.	Average Strength in lbs. per square inch.	
		Adhesive.	Cohesive.
1	Ordinary cement, age 7 days.	59	532
2	" " " "	51	336
3	Fine cement sifted through No. 176 sieve, age 7 days	94	428
4	" " " "	57	345
5	" " " "	65	500
6	" " " age 28 days.	105	500
7	" " " "	109	387
8	" " " "	84	428
9	" " " "	110	309
10	" " " "	85	320

its rejection, while its cementitious strength was considerably above the average of good cements.

The next point requiring investigation is the effect of quick and slow setting on the adhesive strength, which is capable of being developed within the limits of the time available for ordinary testing purposes. Whether the time occupied in setting affects the ultimate strength of adhesion or otherwise must be reserved for future investigation.

Table XII. contains some of the author's experiments relative to this part of the subject (p. 240).

It will be noticed that, with one or two exceptions, the quick-setting cement manifested a greater development of adhesive strength than the slow, while in the case of cohesive strength quick-setting seems generally to produce an opposite effect. In experiments 1, 3, 5, 7, and 8, slow setting was produced by air-slaking. In Nos. 2, 4, and 6, the cements used were sent by different manufacturers as samples of quick and slow-setting cement, and were not exposed to atmospheric influence.

The time of setting was arrived at by the following means: A vertical steel needle moving freely in guides, and having a flat point $\frac{1}{16}$ inch in diameter, was loaded so as to weigh 1 lb. When the pressure of the point made no visible mark on the surface of the gauged cement it was considered to be set. This is approximately the same pressure as that of the finger-nail, but it has the advantage of being more definite and reliable. Nos. 7 and 8 were samples of the same cement, and tend to show that, although the cementitious strength of the slow-setting samples developed slowly in the shorter interval, it subsequently appeared to gain on that of the quick-setting. In the examples referred to, the quick-setting gained only 3 lbs. in the second three months, while the slow-setting increased 20 lbs. in the same period. Experiment No. 2 was an extreme case, the cement showing incipient signs of hardening before the gauging was completed. The proportion of water used in gauging was limited to that required in each case to bring the cement to the same consistency.

The effect of very rapid setting is apparent in the case of orchard or quick-

TABLE XII.—ADHESIVE STRENGTH OF QUICK AND SLOW-SETTING CEMENT. Test-pieces, sawn limestone.

No.	Degree of pulverization.	Age.	Time setting in Air.	Average strength in lbs. per square inch.	Remarks.
1	ordinary ..	7 days ..	40 mins.	57	As received from makers.
"	" ..	7 " ..	8 hours.	29	Cooled by air-slacking.
2	fine ..	7 " ..	10 mins.	58	As received from makers.
"	" ..	7 " ..	5 hours.	85	" "
3	" ..	7 " ..	40 mins.	101	" "
"	" ..	7 " ..	3 hours.	41	Cooled by exposure to air.
4	ordinary ..	7 " ..	1¼ "	46	As received from makers.
"	" ..	7 " ..	3½ "	33	" "
5	" ..	28 " ..	40 mins.	71	" "
"	" ..	28 " ..	24 hours.	48	Cooled by exposure to air.
6	fine .	28 " ..	10 mins.	67	As received from makers.
"	" ..	28 " ..	5 hours.	121	" "
7	" ..	13 weeks ..	30 mins.	110	" "
"	" ..	13 " ..	14 hours.	71	Cooled by exposure to air.
8	" ..	6 months ..	30 mins.	113	As received from makers.
"	" ..	6 " ..	14 hours.	91	Cooled by exposure to air.

Note.—"Fine" cement was that which passed No. 176 sieve.

setting Medina, some samples of this cement showing an average adhesive strength of only 10 lbs. per square inch after seven days' immersion. Similarly, plaster of Paris had a strength of 12 lbs. per square inch after twenty-eight days in air, and Keene's cement 18 lbs. per square inch after seven weeks in air.

As regards a seven or twenty-eight-days' standard test, quick-setting Portland cement can be dealt with either by providing that it shall bear a somewhat higher strain, or by bringing the time in setting within defined limits by air-slaking; the former might possibly lead to complication, the latter is apparently more likely to meet the requirements of the case. The probability is, however, that if a carefully fixed standard of cementitious strength were generally adopted, neither of the alternatives mentioned would have to be resorted to, manufacturers finding it to be their interest to produce cement of sufficient uniformity as regards setting, and fit for immediate use.

In connection with this part of the subject, the proportion of water used in gauging requires consideration. As in the author's system of testing so small a quantity of cement is gauged, he at first used a glass dropping-tube, furnished with a small flexible tube and pinch-cock, the weight of the drops being previously ascertained; the weight of cement to be gauged was generally 200 grains. However, the proportion of water that would enable the cement to be spread easily and uniformly on the test-pieces varied slightly with almost every sample, and the fine-sifted cement required more water than the same cement unsifted. The weighing of the water was therefore abandoned as introducing complications and refinements unsuitable to the practical requirements of a standard test. In all the tests recorded in this paper (unless otherwise specified) the cements were gauged to approximately the same degree of consistency, an operation which involves but little skill or experience. The test-pieces were also immersed in water previous to making the samples, and the cement was applied while the surfaces were wet.

It was noticeable, in the case of the longer testing-periods, that after fracture the cemented surfaces of the test-pieces, and the thin wafer of cement between them, were quite dry; and in the case of wrought iron the surfaces were clean and bright, exhibiting no signs of oxidation; these and other considerations would lead to the conclusion that after taking the necessary quantity of water into combination, the cement resists all further absorption.

The length of time of setting in air is complicated by the effect produced upon it by heat and humidity; four samples of

the same cement were gauged with the same proportion of water, two of them being placed in rather warm, dry air, the others in cool and somewhat damp air, when the former set in twenty-seven minutes, the latter in four hours, the needle test being used in each case.

Such interferences are avoided in the author's system, by immersing the test-pieces immediately after the samples are made.

There appears to be a considerable difference in the hardening produced in air and water in the same time; for example, one cement of good quality was gauged in the usual manner, part being replaced in air and part in water; the former set in three hours. On examining the samples eighteen hours after gauging, the testing-needle, when loaded with 2¼ lbs., produced a visible mark on the sample immersed in water, but required to be loaded with 14¼ lbs. to produce a similar impression on the sample which had remained in air. As hydraulicity is the most important feature in Portland cement, if it should become necessary to take the time of setting into account, it would perhaps be more consistent and useful to note that time with respect to water rather than air.

Table XIII. contains some of the author's observations of the relative time occupied by cement in setting in air and water, ascertained by the test-needle before referred to.

Nos. 1 and 7 were sent by manufacturers as samples of their quick-setting cement, Nos. 2 and 8 of their slow-setting; Nos. 3 and 4 were from the same cement, but gauged with a minimum and maximum amount of water respectively.

The only inferences that can be drawn from these experiments appear to be that fine-sifted cement sets faster, both in air and water, than ordinary cement, and that no definite relation exists between the respective times required to set in air and water. To ensure accuracy in the above results involved much time and trouble, and it would be advisable to eliminate such observations from any universally adopted tests.

The influence of water in gauging, on the cementitious strength, is somewhat capricious; an excess of water frequently produces an increase of strength compared with cement gauged very dry. Sometimes, however, the samples possessed the same strength in both cases, the samples being, in every instance, immersed as soon as they were made.

The strength of adhesion of Portland cement to different substances varied considerably; the roughness or smoothness of the cemented surfaces, however, did not affect the strength as much as had been supposed.

Table XIV. contains most of the results obtained by the author relative to this part of the subject.

TABLE XIII.—RELATIVE TIME OCCUPIED BY CEMENT IN SETTING IN AIR AND FRESH WATER.

No.	Temperature. Fahrenheit.	Time required to set in air.	Time required to set in water.	Remarks.
	°	H. M.	H. M.	
1	41	1 35	3 30	Ordinary cement.
2	41	3 15	4 30	" "
3	50	0 35	2 30	" " gauged very dry.
4	50	1 40	2 45	" " " very wet.
5	50	0 23	0 55	Sifted through No. 176 sieve.
6	53	0 30	1 15	" " " " gauged rather dry.
7	54	0 9	0 20	Special quick-setting.
8	53	5 0	22 0	" slow-setting.
9	55	0 20	2 0	Ordinary cement.
10	34	3 0	16 0	" "
Average.....		1 38	5 34	

No. 5 similar cement to Nos. 3 and 4, but sifted.
No. 6 similar cement to No. 2, but sifted.

TABLE XIV.—STRENGTH OF ADHESION OF PORTLAND CEMENT TO VARIOUS MATERIAL.

Material.	Average adhesive strength.				Remarks.
	7 days.	28 days.	13 weeks	6 months.	
Bridgewater brick..	19	..	..	..	Ordinary cement.
" " ..	24	66	..	..	Sifted through No. 176 sieve.
Slate (sawn) ..	49	..	..	..	Ordinary cement.
" " ..	53	82	..	62	Sifted through No. 176 sieve.
Portland stone ..	26	50	..	..	Ordinary. Fragments torn out of surface.
" " ..	29	62	..	55	Sifted through No. 176 sieve. Fragments torn out of surface.
Ground plate glass..	..	102	113	..	Ordinary cement.
" " ..	..	..	145	..	Sifted through No. 176 sieve.
Plate iron ..	23	68	..	..	Ordinary.
" ..	44	66	..	..	Sifted through No. 176 sieve.
Sandstone ..	..	49	..	..	Ordinary. Fragments torn out of surface.
Polished marble ..	38	..	..	..	Ordinary cement.
" " ..	52	71	..	75	Sifted through No. 176 sieve.
" plate glass..	47	40	70	..	Ordinary cement.
" " ..	55	49	51	..	Sifted through No. 176 sieve.
Granite (chiselled)..	41	..	..	..	Ordinary.
" " ..	78	97	153	..	Sifted through No. 176 sieve.
Limestone, sawn ..	57	78	98	..	Ordinary cement.
" " ..	78	93	116	..	Sifted through No. 176 sieve.

Total number of tests (omitting those of sawn limestone), one hundred and eighty-two.

The best Portland cement, obtained from five leading manufactnrers, was used in the course of these experiments.

The cement adhered to very hard surfaces, such as granite and ground plate glass, with much greater strength than to softer material, as Bridgewater brick, Portland, and limestone.

The strength of adhesion to polished surfaces was also remarkable; in the case of polished plate glass, the average adhesive strength of fine cement in one set of samples was, after twelve months' immersion, 125 lbs. per square inch; the surfaces of the thin wafer of sifted cement joining the test-pieces, particularly in the longer periods, possessing the same fine polish as the glass, so much so as to suggest the use of polished cement for ornamental purposes. Some experiments made with oak, both in air and water, showed so small an amount of adhesion as to be hardly appreciable.

In comparing the results obtained from ordinary cement and that sifted through No. 176 sieve, the relative quantities of the cementing material, and other considerations referred to, should be borne in mind. Some experiments were made in which the cement was gauged with, and immersed in, sea-water, to compare with others made at the same time, in which fresh water was used. The results were as often favorable to one as the other, the averages being almost identical; the number of tests, however, was but forty, and the time from one week to five weeks. A few tests were also made to try the effect, on ordinary cement, of breaking the bond; the results showed an average strength of 8 lbs. and 32 lbs. per square inch, after seven days and thirteen weeks respectively, the bond being broken (*i.e.* the test-pieces disconnected and then replaced in position) twenty-four hours after the samples were made, but the limited number of experiments considerably diminish the value of these results.

The most suitable shape for the test-pieces had to be determined by experience, involving repeated trials; the first shape suggested was that ultimately adopted, namely, cruciform. It was, however, discarded at first, owing to the want of a suitable testing-machine. In the preliminary experiments a slab of stone was introduced into the neck of the ordinary cohesive sample, an arrangement which, unknown to the author, had been adopted by Dr. Michaëlis about the same time. This was found cumbersome

and tedious; it was also difficult to ensure perfect contact between the stone and cement, and it almost precluded any lengthened series of tests with the fine and coarse particles of cement, owing to the time required to sift so large a quantity as would be necessary. Cubes of stone, with holes drilled in the sides to receive suitable clips were next tried, but they were also cumbersome and expensive, and the results likely to be unsatisfactory. The majority of the experiments referred to in this paper were made with test-pieces, one of which was 2 inches by 2 inches by $\frac{3}{8}$ inch, having a hole rather less than $\frac{3}{8}$ inch in diameter drilled through the center, the other being $1\frac{1}{16}$ inch by $1\frac{1}{16}$ inch by $\frac{3}{8}$ inch. So that, deducting the area of the hole, the cemented surfaces had an area of 1 square inch. The cement was placed on the smaller piece, which was then fixed centrally on the larger, and a slight pressure used to ensure perfect contact; a steel pin, fitting the hole loosely, afforded the means of applying the force necessary to separate the test-pieces. This arrangement works satisfactorily, but involves a little trouble in removing the superfluous cement pressed out from between the test-pieces into the hole in the under one, and which, if not removed before testing, might possibly cause the end of the steel pin to be wedged.

To render such a contingency impossible, the cruciform shape was adopted, and the author believes it will be found to meet all the requirements for accurate testing. The testing-machine already described permits the use of either drilled or cruciform test-pieces. The neatness, accuracy, and facility with which tests can be made by the author's method, he ventures to think, will be appreciated by those who have had experience in testing cement by its cohesive strength, either neat or mixed with sand.

The advantages of a universal test, recognized alike by manufacturers and consumers, can hardly be overrated; at present manufacturers are considerably perplexed and inconvenienced by the varying conditions imposed by engineers, and others, but would be willing to work to a carefully arranged practical standard if such were agreed upon.

The total number of adhesive tests made by the author has exceeded one thousand two hundred, a number which, however, must be considered somewhat limited when the nature, properties, and uses of the material are taken into account.

In adopting the adhesive test, the usual specification of the quality of English Portland cement requires to be modified to the following effect:

"The cement shall be ground so that not more than [45] per cent. shall be stopped by a No. [176] silk sieve, and its average adhesive strength after twenty-eight days' immersion shall be as follows:—

Cement passing No. 176 sieve not less than [95] lbs. per square inch.

Cement as supplied for use not less than [75] lbs. per square inch.

Six tests being employed in each case."

If desired a seven days' test can also be specified. Such a modification will involve but little extra trouble to manufacturers, some of whom now produce cement of considerably finer pulverization than that above indicated.

With reference to a standard test, the author's investigations and remarks may be briefly summarized as follows:

That the cementitious or true value of Portland cement can be best determined by testing its adhesive strength.

That the degree of pulverization is probably the only other condition, the practical importance of which will warrant an introduction into a standard system, which should therefore include a standard sieve. That a sieve having one hundred and seventy six meshes to the lineal inch will be found sufficient for all practical purposes.

That so far as regards the limited time which can be allowed in practice for testing before use, an estimate of the quality of cement can be best obtained by testing the cementitious strength of the fine particles capable of developing most of their strength within the period referred to, but that this should not prevent an adhesive test from being applied to the cement in its ordinary condition.

That any complications arising from differences in the adhesive strength produced by quick and slow-setting should, if possible, be eliminated from a standard system of testing. With respect to the time to be allowed for testing, the author

believes that the recognized periods of seven and twenty-eight days can be made sufficient and should be retained, longer periods being desirable, but precluded by the practical inconvenience involved. If the seven-days' test was satisfactory, and necessity should arise, the cement could be used without further delay; but, as a rule, judgment should be reserved until after the result of the twenty-eight-days' test was known. As regards what has been called the "weight-test," the author believes it might with advantage be omitted, but if desired, the density could be ascertained in the manner described by the author in a former paper.

PHYSICAL SCIENCE IN RELATION TO ARCHITECTURE.

By MR. J. SLATER, B. A.

From "The Builder."

Analogous to the motion of fluids is the motion of the air, and upon a correct knowledge of the laws regulating this motion a great deal depends. Although the fact that air is an elastic fluid, ponderable, and subject to the action of natural forces, has been known for many years, it is only comparatively recently that this knowledge has been turned to account in relation to architecture, and that really scientific schemes of warming and ventilation have been devised. Even within our own recollection it used to be considered quite enough to provide an outlet for foul air, and if it was found practically that the foul air refused to avail itself of the outlet, the fault lay in the "nature of things," and the architect and builder were perfectly free from blame. But as soon as it was clearly understood that, after a maximum has been attained, it is just as impossible for air under ordinary pressure to make its way into a room, as for a vessel of a certain size to contain more than a certain quantity of water; or that no matter in what position an opening from an inner apartment into the external air exists, if the temperature of the apartment be higher than that of the external air, the cold air will have a tendency to rush in, rather than the hot foul air to go out—as soon, I say, as these facts were appreciated, it became easy to lay down simple rules of ventilation, which rules have lately been applied with much success. If mechanical means of drawing away the foul air are provided, the place of the air that is drawn away must be taken by fresh air, and it is only necessary to arrange the inlets carefully, and see that the incoming air is not contaminated, to insure good ventilation. To take another instance, which was forcibly brought home to us all by the terrible Tay Bridge disaster, the pressure of air in motion—that is, of wind—on the roofs of buildings, is a subject well deserving scientific study. Fortunately, in this country, we have not to take such excessive precautions against wind as in other climates; but the inconvenience and danger caused by a high gale in London are very serious, and it is probable that a little extra care would make all roofs much less likely to be stripped by the wind than is now the case. The effect of a gale of wind acting upon a sloping roof is two-fold; it never strips off tiles or slates at once, but any gust of wind of exceptional force is followed by a momentary vacuum, during the existence of which the atmospheric pressure inside the roof is greater than that outside, and this being the case, the tiles or slates, if simply nailed to battens, are lifted at the weakest point, their edges, when a following gust strips them off. If this theory is correct, it follows, as a matter of course, that tiles or slates tightly nailed to close boarding must be much better able to resist the interior force tending to lift them up than if only nailed to battens. This turns out practically to be the case. There is only one other matter in connection with the air that I would mention, and that is, that the state of the air in any building materially affects its acoustic properties. Researches and experiments made by

Professor Tyndall and others, have proved beyond question that the waves of sound are most interfered with when they have to pass through strata of varying densities, and hence there is no doubt that the more effectually we ventilate our public buildings the better will their acoustic properties be. A knowledge of the scientific principles which govern the transmission of sound will enable us to prevent the passage of sound through walls, which is one of the greatest annoyances that dwellers in terraces have to put up with, and if the habit of living in flats should increase, this question will become even more important. I have frequently been struck with the small effect pugging under floors has in preventing sound being heard in the lower rooms, and this is because the pugging is nearly always too tightly packed. Any loose substance, such as sawdust or soft hair felt, in which the vibrations of the air lose themselves, and get broken up, would have far more effect; and it would not be a difficult matter to arrange party-walls so that they should be absolutely impervious to sound. *Optics* is another branch of science that immediately affects us, as the laws of the incidence and reflection of the rays of light must govern the size, and more particularly the exact position, of windows in any building, and in town architecture the value of a building depends very largely on the amount of light obtained for the various rooms.

I must now say a few words on the subject of that combination of the various branches of science to which I have already alluded, known as *Sanitary Science*. This was announced to us a few years ago as a new gospel, but it emphatically is nothing more than a knowledge of Nature's laws. This subject has been treated so exhaustively at the Institute within the last twelve months, that I shall not occupy your time to any extent this evening upon it. Sanitary science is a striking example of the way in which all branches of physical science are allied to and bound up with one another. As was remarked by an eminent scientific man a few years ago—"No one science is so little connected with the rest as not to afford many principles whose use may extend considerably beyond the science to which they primarily belong," and no one can possibly tell how our common every-day household arrangements may be affected by any new discovery in science, remote as it may appear at first. Nothing could have seemed less likely to affect house-planning and the sanitary arrangements of a building, than the researches of an eminent French chemist into certain diseases of animals, and yet it is upon the discovery of M. Pasteur that these diseases were caused by the presence of minute germs in the atmosphere, which upon finding a suitable *nidus* became active death-bearing organisms, that the whole germ-theory of disease rests; and this theory, as soon as it was proved to be scientifically accurate, gave the clue to the cause of that fatal disease typhoid fever—a disease which modern civilization, in the shape of extensive systems of drainage, rendered more fatal than it ever has been before, because it made its approach more insidious. Dirt and filth of all kinds are perceptible at once, and can be easily removed; but sewer gas, which will find its way into a house, however clean it may be kept, unless certain precautions are taken, is a far worse enemy; but this enemy can now be attacked with a certainty of success, the precautions necessary to be observed to prevent its entry into our houses being perfectly well known and easily carried out. Until, however, it was known that that this sewer-gas brought with it the germs which caused typhoid fever, all attempts at improving our system of drainage were abortive, because no one knew what had to be guarded against. The condition in which a number of large houses in the West End are now, or were till very recently, is a striking proof of the evil that may be done through want of accurate scientific knowledge. There can be little doubt that without ventilation of the drains, and the cutting-off of all house-drains from the main sewers, an elaborate and complicated system of drainage, like that of London, is the most noxious and pestiferous lethal engine that could be devised, and that we are now able to escape from it is solely due to the progress of physical science. As I have already referred to that part of sanitary science which relates to ventilation, I need not allude to it further; but I must say a word or two as to

Warming. Now the phenomena of heat are a great deal more complicated than many people suppose, and if I were to attempt to explain the scientific principles involved in the transmission of heat, I should most probably lead you astray in a fog of my own creating; but if any one wants to investigate the subject for himself, he cannot do better than consult that admirable text book on the theory of heat by Clerk-Maxwell. It, is however, only quite recently that these scientific principles have been recognized in the manufacture of stoves; but the Smoke Abatement Exhibition has doubtless done much good in this respect, as it has led people to think about the best mode of combustion, and the best method of radiating heat. Recent investigations have shown that light and heat are one and the same thing, but perceived by us through a different channel, and the "theory of exchanges," as it is called, explains why we use polished silver for a teapot, lampblack for stoves, and why we whitewash the roof of a house to keep it cooler in summer, though it is not generally known that the same application tends to keep the house warmer in winter by diminishing its power of radiation. While on this subject I will briefly refer to one very important fact. If the air through which radiant heat passes be perfectly pure, it is almost completely diathermanous; that is, it does not get heated itself, although it transmits the radiations; but the more impure it becomes, the more it stops the radiations, and takes up heat itself. Hence, the purer we can maintain the air in any place of assembly, and the freer from dust, the less effect will the heat which is being radiated into the room have in raising the temperature of the air itself. This shows the great desirability of filtering by means of horse-hair, wadding, or something of that sort, all the air which passes into a room through the ventilating openings.

I have left to the last that branch of physical science the practical developments of which are of most recent birth, and yet which bids fair to be of the greatest importance to mankind, and some knowledge of which will soon be a necessity for architects: I allude to *Electricity*. Although it is many years since the phenomena of electricity were first observed, and their wonderful character commented on, it is only within the last few years that its properties have been turned to practical account; but lately the progress has been so rapid that there can be little doubt we are on the brink of a more gigantic revolution than the one effected by the invention of the steam-engine, in its practical form rather more than a hundred years ago. The number of points at which our work is brought into contact with the inventions of electricians is increasing daily. A few years ago electric bells were about the only things in connection with houses that called for any knowledge of the subject, and these were generally looked upon as expensive toys; but there are now so many different patents for electric bells, and the simplicity of the system is becoming so widely known and appreciated, that I suppose there are few of us who have not been consulted on the subject by clients, and a slight acquaintance with the principles involved. enabling us to form an opinion as to the probability of a battery lasting, as to the good or bad method of insulating the wires, and various other points, is very desirable. otherwise we are completely in the hands of the men whom we employ, and are unable to exercise the slightest supervision over the work. But the subject that is now engrossing so much attention is the lighting of houses and shops by electricity; and you may be sure that before long the question as to the best method of artifically illuminating the new buildings we design will be one that every architect will be expected to give an opinion upon. Electric light systems are divided into two great branches,—the arc-light system and the incandescent systems,—and the question as to which is the more suitable in any particular case will have to be decided according to the conditions which have to be complied with in that case; hence some knowledge of the advantages and drawbacks of each system is essential. Before leaving the subject of electricity, I may mention the report, recently printed, of the Committee on Lightning Conductors, which is a good example of the benefit arising from a combination of scientific with architectural knowledge. Any one who carefully studies that report will gain a knowledge of the subject that it would

have been absolutely impossible to acquire before its publication.

Let me now mention a matter which appears to me of considerable importance to our profession, but which I can only glance at now,—and that is, the preliminary education of an architect. I have a very strong opinion that the majority of architectural students leave school too early. We call ours a profession, and rightly so, as it is one of the most honorable and arduous of professions. If a boy is destined for the profession of law or medicine, not only is he kept at school till he is eighteen or nineteen years of age, but in nine cases out of ten, he has, in addition, a university course, if not at one of the older universities, at such institutions as University College; but it is no uncommon thing for boys to be articled to an architect at fourteen or fifteen years of age, before the preliminary education can possibly have been completed; and I believe the results of this system are altogether bad. No amount of after-study can compensate for the loss of the two or three years at school or college after the age of sixteen. The compulsory examination recently set on foot by the institute will, I hope, do much to obviate this, and I should be glad to see the scheme of examination framed so as to offer a premium for having passed certain public examinations. For example: that candidates who have passed the senior Oxford or Cambridge non-gremial, or the London matriculation, should be exempted from taking certain simple scientific and literary papers that would otherwise be compulsory, and in this way I believe much good might be done. I have endeavored to show in how many ways a knowledge of physical science may be of advantage to an architect, and I can quite imagine that some such objection as this has occurred to your minds while I have been speaking: "Granting that such knowledge would be beneficial, still the range of subjects is so vast that it would be impossible to gain a thorough acquaintance with them." This I fully admit; but my point is, that a slight acquaintance with these subjects is much better than none at all. As was pointed out by Dr. Siemens some few months ago, a little knowledge is *not* a dangerous thing under certain conditions: these are that the little knowledge be well digested, and that its limits be kept always clearly in view. Although it may seem paradoxical to say so, yet it is a fact that a little knowledge of a subject will often enable a man to see clearly that he knows nothing at all about certain branches of that subject; whereas, if he had no knowledge at all, he might think he knew all about it. There are so many matters closely allied to architecture which are daily becoming more and more important, for which supplementary contracts are obtained, that if we are absolutely ignorant of them, we are wholly at the mercy of the individuals who are employed to do the work, so that I do not think any one should be deterred from gaining a slight acquaintance with scientific subjects because of the impossibility of mastering them. Just as a slight knowledge of a language will not enable us to go at once and read the books written in that language, but will, at any rate, help us to verify a quotation; so a slight knowledge of science will assist us to understand somewhat of its language, and most important of all, will prevent our being the victims of gross deception. I remember hearing a friend of mine, who has had a thorough scientific training, once make a remark which struck me as being a very forcible one. He said,—"There are a great many branches of science that I know nothing about, but I will defy any man to talk nonsense to me on any scientific subject whatever for five minutes without my finding him out." Another objection has probably occurred to you of this kind. What is the use of an architect's taking time to study certain subjects, when he can always call in a specialist who has made an exhaustive study of the same subject? This objection is a very plausible one, and requires to be examined somewhat in detail. In the first place, questions often crop up unexpectedly, which require a decision of some sort to be arrived at at once, and it frequently happens that a specialist is not at hand to advise. In such a case, a slight acquaintance with a subject might enable the architect at any rate to meet the difficulty temporarily, and then, if it should happen that an expert has to be called in, no harm would have been done. Then comes the question of expense,—which is frequently a serious matter to the client,—and here I am touching on a

subject that was referred to a few months ago by Mr. Cole Adams in his interesting paper on Barnacles. Specialists invariably charge heavy fees, and quite rightly. If a man has taken the trouble to master thoroughly any one branch of his profession, and limits his chance of employment to that branch, he ought to charge highly for his knowledge and experience, and I quite admit that in many cases an architect would act wisely to call in a specialist to advise with him, just as a medical man calls in a consulting physician in urgent or difficult cases; but as the family doctor ought to be able to treat all cases not requiring serious and exceptional treatment, a patient would have good cause for complaint against his medical man were he to advise calling in a physician for every little ailment: so it seems to me a client may justly complain if he finds his architect unable to decide what course to adopt in matters of drainage and other scientific subjects which do not present any great difficulty. He imagines that for the fee which he has to pay he is going to obtain skilled advice and assistance throughout the whole of the work which he entrusts to his architect, and will be very likely to grumble at having to pay several extra guineas for an extraneous opinion. There is further one very decided danger in consulting a specialist. You have probably all heard of the physician who discovered a certain disease that was named after him, and after his discovery it is said that no patient ever consulted him, but he found out that the man was suffering from that very same disease; just in the same way a specialist who has made any one subject a special study is almost certain to have strong opinions as to the causes which lead to the existence of a certain state of things, and he will therefore be very likely to find out the existence of these causes, and to advise expensive remedies which *may* not really have been required; whereas an examination by an unbiassed man who has had a scientific training, and is not apt to jump at conclusions hurriedly, may very possibly discover some simple cause for what is wrong that a very slight expense may put right. What is likely to be the effect on the general public,—and you must remember that the general public are made up of individuals, and that the way in which we treat our individual clients is a factor in the estimation in which the profession as a whole is held by the public.—what is likely to be the effect on the public if they find that when the architect is consulted on some faults of drainage, he says, "Oh, Mr. So-and-So is an authority on this point, and you had better call him in," or when he is asked his opinion as to the cause of defective ventilation, he refers to some other eminent authority? Will not the public gradually get to have a low opinion of the profession generally, and begin to question the necessity of employing an architect at all? Are not some of the articles that have recently appeared in some of the papers a proof that this opinion is becoming held more or less? Ought we not, then, to do our utmost to prevent such an opinion gaining ground? We can never tell what matters may be referred to us in the ordinary course of our practice, and we must always remember that the specialist knowledge of yesterday is the common knowledge of to-day.

It may possibly be objected that there are many cases such as I have mentioned which do not come within the legitimate province of an architect, and that if he were to attempt to qualify himself for undertaking such work, he would only be intruding into the domain of the engineer. I hold that any work appertaining to the structural stability of a building, to its sanitary condition as regards drainage, warming, or ventilation, and generally to its suitability for the purposes for which it is intended, is most distinctly within the province of the architect, and if he gives up this to others and endeavors to retain only the artistic part of the work, he will soon find that this is gone too. We do not find that engineers make any scruple about designing the ornamental features of a bridge or any other erection they may have to construct. We find auctioneers and surveyors taking to themselves the title of architect, and designing the houses that are to cover the estates which they have to sell and develop. We are beginning to find plumbers and builders calling themselves sanitary engineers and architects; and how is it that they gain the ear of the public? Simply because the public think that if they go to

a man of this sort they go to a practical man; whereas, if they go to an architect they will find only an artistic *dilettante* who has to go to some one else for advice upon practical points. Depend upon it, if we are to hold our own in the keen competition which now exists, it will not be by taking any so-called high ground as to our being artists and nothing else, but by convincing the public that we are practically acquainted with every branch of our profession, that we can meet the plumber and the surveyor on their own ground, and by showing that, in addition to practical knowledge, we can give that artistic finish which is the result of a cultured education, and which can never be acquired by any one without the patient study to which the early years of the architectural student's life should be devoted. There can, however, be no greater mistake than to think that there is anything derogatory to the true artist in being practical, and in having a knowledge of science. As a proof of this I should only need to point to that admirable address delivered so recently by the leader whose loss we all deplore, to show how Mr. Street, artist as he was in his every fibre, worked strictly on a scientific basis, and his works are a standing proof that the true artist never sacrifices strength to beauty, or lays on ornament for the sake of doing so. But as a matter of fact the greatest artist cannot dispense with scientific knowledge. The sculptor may have the highest manual dexterity, the figure painter the lightest and most delicate touch with the brush; but without a knowledge of the anatomy of the human figure each will be powerless to produce a statue or a painting that shall live as a thing of beauty for ever. So with the landscape painters; the greatest of them are those who live with nature and study her inner workings, and not only her surface aspects; who watch the growth of flower and shrub, and note the effect upon them of storm and sunshine, who ascertain the causes by which the various tints in the atmosphere are brought about,—in a word, who make themselves thorough masters of one or more branches of physical science.

The value of scientific training is by no means limited to its direct results; those that are indirect are of equal importance. A man who has acquired a scientific habit of thought will always exercise a close observation of the facts that come under his notice; he will feel that of the causes which have led to the existence of any state of things that he may be called upon to examine, those that lie on the surface, and are most obvious, may very probably not be the real ones; he will not allow himself to be led away by superficial similarities; and, above all things, he will not be hasty in jumping at conclusions. Useful as these qualities are to every one, they are of especial value to an architect in what I may call the collaterals of his profession. When once a man gets into regular practice, he will find that designing buildings forms but a part—sometimes a small part—of his work, which frequently consists of reporting upon the condition of buildings, settling disputes, giving evidence in courts of law, and such matters as these; and herein the indirect qualifications, which are the results of scientific study, will be of the utmost service.

I have thus endeavored to show you, very imperfectly, how intimately we architects are interested in the advance of physical science. As I said at the commencement, so I would repeat now, that I hope I shall not be considered as in the least opposed to our being artists: it has been my endeavor to show that art and science are not antagonistic, but rather twin sisters who ought never to be separated, and it is to any tendency to separate the two that I am opposed. Captivating as art is to her votaries, science is equally so to hers; and, in conclusion, I think I may safely promise this, that he who takes up the study of any branch of science connected with architecture will never regret having done so, but will find in the pursuit of it growing delight and an ever increasing fascination.

English milling engineers are introducing square rope belts, which are said to be very suitable for transferring power. They are made in strips with "step" joints, screwed together; the sides of the rope leaving the pulley groove without loss of power. It is stated that a one and a-half inch rope, at 4000 feet a minute, has driven over 100-horse power.

A SECOND SUEZ CANAL.

From the "Nautical Magazine."

THE question of providing additional means of transit through the Isthmus of Suez bids fair to excite almost more interest, and to arouse even more national feeling than were produced by the original scheme for the construction of the present canal. For some time past it has been evident that increased canal accommodation must be provided. At the recent meeting of the Association of Steamship Owners engaged in the Eastern trade it was stated that the traffic had increased from 4,500,000 tons in 1880 to 7,000,000 tons in 1882. And at the last half-yearly meeting of the Peninsular and Oriental Steam Navigation Company, the chairman, Mr. T. Sutherland, made serious complaints with regard to the inadequacy of the canal to meet the growing requirements of the Eastern trade. It was stated that the company are now compelled to start their vessels from London twenty-four hours earlier than formerly, in order to insure their reaching Suez in time for the arrival of the mail from Brindisi. This is entirely owing to the increasing delays in the canal, something like three days being now occupied in traversing a distance of ninety miles.

In short, the necessity for an extension of the present accommodation is every day becoming more pressing. There is every reason to believe that our trade with the East and Australia is still far below the highest point it is destined to reach. With a fuller development of the means of internal communication in India and China, there would seem to be no definite limit to its further growth. For example, it is estimated by competent authorities that India will be able to double her present export of wheat within the next few years. Great reductions are being made in the rates charged on the different railways, and it seems likely that before long Indian wheat growers will be able to enter into a serious competition with growers in America. Already India sends us 20,000,000 cwt. of wheat, and if this amount were doubled her export would be equal to two-thirds of the total wheat imports of the United Kingdom. The great increase which is taking place in the amount of shipping engaged in the East shows plainly that trade generally in that part of the world is in a flourishing state, and fully justifies the assumption that no long period will elapse before 10,000,000 tons of shipping per annum will have to be passed through the canal.

The question now calling for decision is not whether additional accommodation is required, but who is to have the privilege of providing it. That M. de Lesseps should assert an exclusive right on the part of the present company to carry out any further works which may be necessary is not surprising. The position of the company, as defined by the concession granted by Said Pacha in 1854, is certainly a strong one; but, in addition to this, the undertaking has proved successful, even beyond the most sanguine expectations of its talented projector, and it is not to be supposed that any scheme for constructing a rival canal will be regarded with indifference by those who are receiving handsome dividends from the present monopoly. Sixteen per cent. was the rate of profit for 1882, and M. de Lesseps, we believe, not long since declared his intention of "making the fortunes" of the present shareholders. It is evident, however, that the claims made by M. de Lesseps on behalf of the existing company will not be allowed to pass unchallenged. The British shipping trade is beginning to feel, not only the inconvenience arising from the inadequacy of the canal to the requirements of the traffic, but also the weight of the dues from which the "fortunes" of the shareholders are being derived. Moreover, the payment of interest at the rate of 16 per ct. upon an investment that may be regarded as perfectly secure is not without an influence on capital; and, as there are no practical difficulties which would impede the construction of further works, it is natural that capitalists should show a desire to take advantage of the opportunity now presented

for obtaining a share in the general undertaking.

The problem to be solved by the various authorities concerned is doubtless somewhat intricate, involving as it does, questions of private right, of national feeling and of grave international importance. The position of the present company is tolerably clear. M. de Lesseps relies entirely on the concession made by Said Pacha in 1854 which conferred on the company the exclusive right of making and maintaining a canal through the Isthmus, and extended this privilege for a term of 99 years from that date. The Egyptian Juridical Committee who have recently had the matter under consideration have expressed the opinion that this concession places the company in an unassailable position; but it seems to us that, in one sense, their position is even too good. If Said Pacha had granted a monopoly for a moderate term, the grounds for raising awkward questions with regard to their precise rights would have been somewhat less favorable than they are under the present conditions. The aasumption that Said Pacha, who happened to be the deputed ruler of Egypt in 1854, had the power to settle for a period of 99 years a question of the gravest importance to the whole world, is one by no means easy to uphold by force of argument. If he had merely authorized the construction of a new railway across the Isthmus, and had given a guarantee to the proprietors that for a term of 99 years no canal should be made which would compete with their undertaking, even M. de Lesseps would doubtless have been able to find good reasons for disputing the soundness of the arrangement Yet such a case would have been precisely similar to the present.

As regards the construction of any further works, the position of the canal company is not, however, so strong as would at first appear. In the first place they can do nothing towards enlarging the channel without the consent of the Egyptain Government. The canal could not be widened unless a grant of additional land were made, and whether this would be allowed or not would be for the Egyptain authorities to decide. M. de Lesseps is well aware of this, and he also knows that, as the British Government are at present complete masters of the situation in Egypt, it would be useless for him to seek any further concession without their approval Moreover, by Article 2 of the concession of 1854, the Egyptian Government reserved the right to appoint the Director of the company, so that practically it has the power to exert a very material influence on the policy to be adopted with regard to the future management of the undertaking.

But, as a matter of fact, this question is not to be decided by any verbal, or semi-legal, quibbles with respect to the exact import of any concession that may have been granted by Said Pacha. The Suez Canal has now become a great international highway, and the point at issue is, whether a particular monopoly is to be allowed to exist to the advantage of the whole civilized world. The pretension of M. de Lesseps that the Canal Company should have the power to dictate terms with regard to the right of way through the Isthmus for a period of 99 years, is too extravagant to be maintained. Even during the recent Egyptian war it was found necessary to interfere with the independence of the company, and what was done then would certainly be done again whenever the necessity of the occasion arose. The so-called private rights, whether of individuals or of companies, cease to exist as soon as they clash with national interests, and from the working of this rule the Suez Canal Company will unquestionably not be exempt.

As regards the passage through the Isthmus of Suez there are two distinct questions involved. In the first place the requirements of the shipping trade call imperatively for a large extension of the present accommodation, as well as for a reduction in the present heavy dues; and, in the second, in the interests of this country it is essential, as stated in Article 1 of the Draft International Agreement issued by the Foreign Office in January last, that the canal shall "be free for the passage of all ships in any circumstances." With respect to the first consideration, the construction of a second canal seems to be the only course for providing a satisfactory solution of the present difficulty. M. de Lesseps calculates that by means of certain alterations in the existing canal, accommoda-

tion could be secured for a traffic of 10,000,000 tons per annum; but, even if this could be done, the provision would be only temporary. It is tolerably certain that, within the next few years, the Eastern shipping trade will surpass this amount if due facilities for its development are provided; consequently it is useless to look to any enlargement of the present canal for a permanent settlement of the question. It appears to us that nothing short of an arrangement which would enable the traffic to be maintained continuously in both directions can be deemed satisfactory; and it is evident that only by means of a second canal would this be possible. As long as only a single channel exists there will always be the risk of delays and temporary blocks in the traffic from a variety of causes, and for this reason, if for no other, the construction of a second canal may be regarded as highly necessary.

But, in addition to the question of convenience, there is also the subject of the canal dues to be considered. And here it must be borne in mind that, if any appreciable reduction is to be made in the charges which now weigh so heavily on the Eastern shipping trade, it is essential that any additional means of communication which may be provided should be under the control of an independent company. As long as a monopoly exists the Isthmus of Suez will continue to be the mine of wealth it is at the present time, and the shareholders who control the right of way will certainly not cease to endeavor to "make their fortunes" at the expense of the marine carying trade. If the United States, by any ill-judged concession, had granted to the first Atlantic Telegraph Company the sole right of laying submarine cables between their ports and Europe, for example, it is easy to imagine the nature of the inconvenience that would have resulted. And the Suez Canal is an exact parallel. A monopoly in the one case would have long since proved intolerable; and in the other there is nothing which can possibly render it less burdensome.

It is evident that shipowners in this country are now fully alive to the true position of affairs with respect to the Suez Canal. At the recent meeting of steamship owners interested in the Eastern trade, the representatives of 3,000,000 tons of shipping passing through the canal per annum were present, and a sum of £20,000 was at once subscribed towards the expenses of preliminary inquiries, with a view to the commencement of a new undertaking. And we believe there is at present a vast amount of capital ready for investment as soon as the construction of another canal has been decided upon. That this should be the case is natural, for the rate of profit is certain to be good, while the risk is practically *nil*.

As regards the national interests involved in this particular question, it is clear that the English Government are now masters of the position, and that they will be almost compelled by the force of circumstances to turn their advantage to account. Full credit must be given for the honesty of their declaration that Egypt is to be occupied only temporarily; but the present aspect of affairs seems fully to warrant the assumption that, unless some unforeseen contingency should intervene, our occupation will be prolonged indefinitely. At all events an abandonment of the country is at present quite out of the question, and it would be deplorable if England were not to utilize the opportunity now offered for removing what may at any time become a very serious obstacle to the free use of her great Indian route. We are well aware of the importance of a friendly understanding between this country and France; but, in the endeavor to preserve this intact, it is highly necessary that certain plain facts should not be lost to sight. M. de Lesseps is justly entitled to the world's esteem for the courage and genius he displayed in bringing his work to a successful issue, in spite of the opposition he had to encounter from this side of the English Channel, and his French supporters may claim full credit for their sagacity in assisting to carry his scheme into effect. We have to admit that England's former policy in this matter was erroneous; but our gratitude to the founders of the canal must not be carried to excess. We must now deal with the facts as they stand. And these facts are simple. The Suez Canal has become a maritime highway as important as the Straits of Gibraltar. In consequence of

the growth of British commerce, which supplies four fifths of the total traffic, it has become inadequate to the demands for accommodation. It is the key to England's most important possession; but it is in the hands of an independent company. It is now admitted on all hands that new works must be undertaken, and the question is whether England is to allow this company to hold the right of way through the Isthmus as its own private monopoly, or whether she will insist that when the new channel is cut it shall be placed either under her own direction, or be made subject to an international arrangement which would insure just and equitable treatment for all.

With all due respect to M. de Lesseps, it seems to us that his claim to tax the Eastern carrying trade for the purpose of "making the fortunes" of certain shareholders, is not more defensible than was the practice of the petty German chiefs who, in the middle ages, levied black mail on the vessels passing down the Rhine in front of their castles. There is in this country no desire to deprive the company of its just rights. It is entitled to generous treatment in return for the great services it has rendered to the world, and this we have no doubt it will receive. But that it shall be allowed to have entire control over the right of way through the Isthmus until the year 1953, simply for the purpose of enriching two or three generations of private shareholders, is a pretension altogether too extravagant to be maintained, and one, moreover, which England could not allow without ignoring her most vital interests in the East, nor without completely reversing the policy she has already spent several millions sterling in maintaining.

DEVIATIONS IN COMPASSES OF IRON SHIPS.

By STAFF-COMMANDER E. W. CREAK, R. N.

Abstract of a Paper recently read before the Royal Society.

THE period comprised between the years 1855-68 was one of active research into the magnetic character of the armor-plated and other ships of the Royal Navy, and iron ships of the Mercantile Navy.

Among other contributions to this subject, a paper by F. J. O. Evans, Staff-Commander, R.N., F.R.S., and Archibald Smith, F.R.S., was read before the Royal Society in March, 1865, relating to the armor-plated ships of the Royal Navy, and containing the first published results of the system of observation and analysis of the deviations of the compass established four years previously.

From lack of observations in widely different magnetic latitudes the authors of that paper were unable to define the proportions of the semicircular deviation arising from vertical induction in soft iron, and that arising from permanent or sub-permanent magnetism in hard iron.

During the last fifteen years vessels of all classes—except turret ships—have visited places of high southern magnetic inclination or dip, and the analysis of the deviation of their standard compass has been made, showing the constants of hard and soft iron producing semicircular deviation.

The constants of soft iron provide a means of *predicting* probable changes of deviation on change of magnetic latitude for certain vessels of the following classes, and others of similar construction.

1. Iron armor-plated ships.
2. Iron cased with wood.
3. Iron troopships.
4. Iron and steel ships cased with wood.
5. Composite-built vessels.
6. Wooden ships with iron beams and vertical bulkheads.

These vessels were all in a state of magnetic stability previous to the observations which have been discussed, and their compasses have had the semicircular deviation reduced to small values, or corrected in England by permanent bar magnets.

This correction may be considered as the introduction of a permanent mag-

netic force acting independently, and in opposition to the magnetic forces of the ship proceeding from hard iron.

It is now proposed to consider the effects of a change of magnetic latitude on the component parts of the deviation.

Semicircular Deviation.

On semicircular deviation from fore-and-aft forces, time has but little effect, and the greater part of it is due to permanent magnetism in hard iron which may be reduced to zero for all latitudes by a permanent magnet.

A second but small part of this semicircular deviation proceeds from sub-permanent magnetism in hard iron. It is subject to alterations slowly by time, from concussion, and from the ship remaining in a constant position with respect to the magnetic meridian for several days, and is more intensely affected by a combination of the two latter causes.

Deviations from sub-permanent magnetism which have temporarily altered in value as described, return slowly to their original value on removal of the inducing cause.

The principal cause of change in the semicircular deviation on change of magnetic latitude, in corrected compasses, arises from vertical induction in sot iron, which changes directly as the tangent of the dip.

In standard compasses judiciously placed with regard to surrounding iron this element of change is small, and similar in value for similar classes of ships.

With very few exceptions, nearly the whole of the semicircular deviation from transverse forces is due to permanent magnetism in hard iron subject to the same laws as that proceeding from fore-and-aft forces.

In the exceptional cases alluded to, there is a small part due to vertical induction in soft iron, changing directly as the tangent of the dip.

Quadrantal Deviation.

This deviation, caused by induction in horizontal soft iron symmetrically placed, does not change with a change of magnetic latitude. Time alone appears to produce a gradual change in its value during the first two or three years after the ship is launched, when it becomes nearly permanent.

The diminution of the mean directive force of the needle, which is common to all vessels of war, improves slowly at first by lapse of time, and finally assumes a permanent value.

Relative Proportions of Hard and Soft Iron.

It has been found that the relative proportions of the hard and soft iron affecting the standard compasses of twenty five vessels examined differ considerably, even in ships of similar construction.

This difference may be accounted for by the compasses not being placed in the same relative position in the ships considered as magnets of various forms, and containing numerous iron bodies introduced during equipment.

General Conclusions.

The following general conclusions have special reference to the standard compass positions of the six classes of vessels previously mentioned:

1. A large proportion of the semicircular deviation is due to permanent magnetism in hard iron.

2. A large proportion of the semicircular deviation may be reduced to zero, or corrected for all magnetic latitudes, by fixing a hard steel bar magnet or magnets in the compass pillar, in opposition to, and of equal force to, the forces producing that deviation.

3. A very small proportion of the semicircular deviation is due to sub-permanent magnetism which diminishes slowly by lapse of time.

4. The sub-permanent magnetism produces deviation in the same direction as the permanent magnetism in hard iron, except when temporarily disturbed (1) by the ship's remaining in a constant position with respect to the magnetic meridian for several days, (2) by concussion, or (3) by both combined, when the disturbance is intensified.

5. To ascertain the full value of changes in the sub-permanent magnetism, observations should be taken immediately on the removal of the inducing cause.

6. In the usual place of the standard compass the deviation caused by transient vertical induction in soft iron is

small, and of the same value (nearly) for ships of similar construction.

7. The preceding conclusions point to the conditions which should govern the selection of a suitable position for the standard compass with regard to surrounding iron in the ship.

The following note is in answer to a correspondent's query recently addressed to us; the subject, as he says, has not been mentioned in any of the works treating on the Deviation of the Compass:

Practical Rules for the correction of the semicircular deviation at sea when the compass has been previously corrected by magnets. If, in the lapse of time, or through any considerable change of magnetic latitude, it is found that the deviation card no longer correctly indicates the deviation, you can correct the semicircular deviation by attending to the following rules. It is of course taken for granted that you know the use of *Time Azimuths, or of distant terrestrial objects*, in bringing your vessel's head to any of the cardinal points, *correct magnetic;* then you will move the magnets, as required, for two *adjacent* cardinal points, and subsequently test the correction for the remaining two cardinal points.

I. For ship's head brought *correct magnetic* North or South, the correcting magnet lies athwartship, with its N. marked (*red*) end to starboard or port, according to the original deviation. Then proceed to move the correcting magnet as follows:

(*a*) *Thwartship magnet with N. marked end to starboard—*

Ship's head N., with E. dev. (*i.e.* compass N. to starboard) magnet nearer.
Ship's head N., with W. dev. (*i.e.* compass N. to port) magnet further off.
Ship's head S., with E. dev. (*i.e.* compass S. to starboard) magnet further off.
Ship's head S., with W. dev. (*i.e.* compass S. to port) magnet nearer.

(*b*) *Thwartship magnet with N. marked end to port—*

Ship's head N., with E. dev. (*i.e.* compass N. to starboard) magnet further off.
Ship's head N., with W. dev. (*i.e.* compass N. to port) magnet nearer.
Ship's head S., with E. dev. (*i.e.* compass S. to starboard) magnet nearer.
Ship's head S., with W. dev. (*i.e.* compass S. to port) magnet further off.

II. For ship's head brought *correct magnetic* East or West, the correcting magnet lies fore-and-aft, with its N. marked (*red*) end aft or forward, according to the original deviation. Then proceed as follows:

(*c*) *Fore-and-aft magnet with N. marked end aft—*

Ship's head E., with E. dev. (*i.e.* compass E. to starboard) magnet further off.
Ship's head E., with W. dev. (*i.e.* compass E. to port) magnet nearer.
Ship's head W., with E. dev. (*i.e.* compass W. to starboard) magnet nearer.
Ship's head W., with W. dev. (*i.e.* compass W. to port) magnet further off.

(*d*) *Fore-and-aft magnet with N. marked end forward—*

Ship's head E., with E. dev. (*i.e.* compass E. to starboard) magnet nearer.
Ship's head E., with W. dev. (*i.e.* compass E. to port) magnet further off.
Ship's head W., with E. dev. (*i.e.* compass W. to starboard) magnet further off.
Ship's head W., with W. dev. (*i.e.* compass W. to port) magnet nearer.

The character of the heeling error may be well expressed in a *tabular form*, according to whether the N. point of the compass needle is drawn to windward, or to leeward, as follows:

For Heeling Error, on Courses,	When N. end of compass needle is drawn to windward; heel to port gives	When N. end of compass needle is drawn to windward; heel to starboard gives	When N. end of compass needle is drawn to leeward; heel to port gives	When N. end of compass needle is drawn to leeward; heel to starboard gives
Bet. E. & W., through N..	E. or +	W. or −	W. or −	E. or +
Bet. E. & W., through S..	W. or −	E. or +	E. or +	W. or −

And where the ship or steamer may

have taken a *strong* list, owing to a shift of the cargo, substitute "high" side for windward, and "low" side for leeward.

REPORTS OF ENGINEERING SOCIETIES.

AMERICAN INSTITUTE OF MINING ENGINEERS. The Autumn meeting of the Institute will be held in Troy, N. Y., during the second week in October. This meeting will be mainly devoted to the reading and discussion of papers.

Members who wish their papers fully discussed at the meeting can have them printed and circulated in advance, if they are sent to the Secretary early in September.

ENGINEERING NOTES.

SOME of the Russian soldiers have been busy lately. The Jabinsk-Pinsk Railway, 120 miles in length, has been constructed by one corps, and although it was necessary to erect no less than sixty-nine bridges, two of which were of considerable size, the whole line was finished in five months, and cost the Government only £3,400 per mile. The Trans Caspian Krasnovodsk Railway is also making rapid progress, and will be completed as far as Kizil Arvat by the middle of June. In spite of the scarcity of materials, and the obstacles presented by the Trans Caspian steppe, the line will only cost about £4,200 per mile. A *Times* correspondent says it has been found by experience that the storms and sand drifts in the steppe cause very little damage to the railway, only sometimes delaying a train for a few hours.

AT the meeting of the American Society of Civil Engineers in New York, May 16th, Mr. F. J. Cisneros, who recently visited the Isthmus of Panama, presented an informal statement of the progress of the work on the Panama Ship Canal. He stated that the purchase of the Panama Railroad by the Canal Company seemed to promise most excellent results. In reference to the canal, he said that the line had been completely staked, cross sections taken, and the location made and stakes set for definite work for a large portion of the line. The line is entirely cleared and grubbed from Kilometer 40 to the mouth of the Rio Grande, and is rapidly advancing to other points. The valley of the Chagres has been surveyed, and it has been found that the high water lines above the high dam will cover an area of about 6,750 acres, and that the volume of water stored will be about 1,000,000,000 cubic meters. Actual work upon the canal has been commenced at six points. The contractors, Messrs. Slaven & Co., for dredging the canal from Colon, have their first "Hercules" dredge in place, and will commence work directly. The Canal Company has been working with two French machines, at the rate of 1,000 cubic meters per day for each machine. The Franco-American Trading Company has contracted for the excavation of about 10 kilometers of the canal beyond the Bay of Panama. Its machines are being built at Lockport, N. Y. There are now about 6,500 men on the work, chiefly Jamaicans, Carthagenians, and a few Martiniqueans.

SEPARATE SYSTEM OF SEWERAGE.—Mr. Albert W. Parry, M. Inst. C. E., borough surveyor, read a paper on the separate system of sewerage as carried out at Reading. The system could not be regarded as complete, so far as surface water is concerned, as all the sewers are not new. A system of sewers for the disposal and utilization of sewage was completed about seven years ago, and the old sewers, which formerly conveyed both sewage and surface water, are now used only for surface water, and in streets where there were no new sewers new ones are being laid. The urgent need of keeping rain water out of the main sewers had been shown by the sewage being diluted and its volume increased, causing augmented cost and difficulty of dealing with it on the sewage farm. After describing the system of sewerage, he mentioned that the hard rule of excluding all surface water from the sewage sewers was relaxed in cases where there are small enclosed areas in the rear of houses, where a second grate or trap, if fixed for receiving rain water, would offer equal facilities for the emptying of slops. The number of houses was 8,700, the average quantity of sewage pumped was 998,277 gallons per day, and the water supplied to the town was about 1,813,000 gallons daily.

A discussion ensued, which lasted nearly three hours. Mr. Gordon (Leicester) stated he had partially adopted the separate system, and was in favor of getting storm water to the natural outfall for the water of the district. Col. Jones (Wrexham) advocated the separate system, and said that in that way alone could the difficulty of disposing of sewage by irrigation be successfully accomplished. Surface water should go into the drains, and water supplied for domestic purposes only into the sewers. Mr. Jerram (Walthamstow) stated that for two or three years the system had been tried there, and had proved a failure. Sewage and dirty slops were being constantly connected with the surface drains, when repairs were needed, so that it was impossible to work the system satisfactorily. Mr. Lemon (West Ham) declared there was no perfectly separate system carried out in England, and if it were, it would not last a month. It was only applicable to some towns, and only where sewage was applied to the land, or had to be pumped, and then purified by precipitation and some chemical process. It was an extraordinary stretch of authority to compel houses to have drains for sewerage and for surface water. The only extent to which the system could safely and wisely be carried was, in suitable situations, to carry off into the natural outfall the water falling in open streets, that side of the roofs of houses and places under the sole control of the local authority. Mr. Pritchard (Birmingham and London) expressed similar views and Mr. Angell (West Ham) agreed that the separate sys-

tem should be limited to streets, open spaces, and the street sides of houses. It would be folly to attempt to carry it further. Mr. Parry replied at some length, but the general feeling was evidently strongly adverse to anything like an attempt to compel all houses to have two sets of drains, one connected with the sewers for sewage and house slops, and the other for surface drainage and inoffensive water.

THE SOUTH PASS IMPROVEMENTS.—Captain W. H. Heuer, Corps of Engineers, has submitted to General Wright his annual report of the progress of the work on the improvement of the South Pass of the Mississippi River, from which the following extracts have been taken:

"Except for five days in July, 1882, there has been a channel between the jetties having at least a depth of thirty feet of water in it, and the twenty-six feet deep channel in the jetties had during the year, except for nine days in July, 1882, a least width of 200 feet. At present there is a depth of thirty-one feet in the jetties, and the least width of the thirty-feet channel is ninety feet. The least width of the twenty-six-feet channel is 240 feet. In the pass itself there is a channel twenty-seven feet deep, and the twenty-six-feet channel in the pass has a least width of 160 feet. In other words there is now a channel at least 160 feet wide, and having a least depth of twenty-six feet of water in it, from the Gulf into the main river. This is the best channel that has ever been found since the jetties were constructed. But eighteen days' dredging has been done on the work during the year, of which five days was in the pass, nine days in the jetties, and four days on mud lump outside of the jetties. The thirty-feet channel within the jetties has much improved during the year. For a small portion of the year the narrowest part of this channel was only fifteen feet in width. This has increased until now its least width anywhere is ninety feet. The improvement is attributed to the construction of an inner jetty, built parallel to and about 200 feet inside of the east jetty. The length of this inner jetty is 6,810 feet. While the river jetty has improved the channel in the jetties, it has reduced the width of the waterway between the jetties to 630 feet. Before the wing dams, cribs and inner jetty were built the waterway was about 1,000 feet in width. In September last a cyclone passed over the jetties and worked much damage to the east jetty, about one-half mile in length of the concrete wall on this jetty being badly broken, and solid blocks of concrete weighing twenty-eight tons being displaced. The channel within the jetties, however, remained uninjured.

"Surveys made during the year beyond the ends of the jetties extending out to 100 feet depth of water show a very little change to have occurred on what is sometimes called the bar. On the jetties proper no work has been done during the year. Within them work has been confined to building the inner jetty and five wing dams projecting from the east jetty. In the pass proper eleven new wing dams have been built, one at Crane Island, three near Goat Island, and seven near Bayou Grande, varying from 20 to 250 feet in length. At the places the pass was wide and shoaler than in the narrower parts of the pass. In fact, the depth of water in the channel was hardly an inch more than the twenty-six feet of depth required. After the dams were built the current rapidly scoured out the crests of these shoals until a depth of thirty-two feet of water was obtained.

"At the head of the South Pass there is now a fine channel four hundred feet wide and having a least depth of thirty feet. The channels at the heads of Southwest Pass and Pass a l'Outre are also increasing in depth, but the bars at the mouths of these passes are reported as being very shoal. That at Southwest Pass is reported as having only a twelve-feet channel through it, while Pass a l'Outre bar is said to have but eight feet. Both of these passes are now so little used that but little is definitely known about them, except where our surveys cut into them near their heads. During the year ten vessels grounded in the pass, jetties, or near the jetties, but in every instance they were out of the channel, which was wide, deep and practicable.

RAILWAY NOTES.

RAILWAY IMPROVEMENTS.—Mr. Westmacott, in his address to the Institution of Mechanical Engineers, said, in regard to our present railway systems:

"Touching upon speeds, the mind naturally reverts to railway traveling. Here, however, it would seem as if for the present we had reached a maximum. It is surprising how soon the speed of the locomotive was brought up to something approaching its present limit. Geo. Stephenson was laughed at in 1825 for maintaining that trains would be drawn by a locomotive at twelve miles an hour, but the Rocket herself attained a speed of twenty-nine miles an hour at the Rainhill competition in 1829, and long afterwards ran four miles in 4½ minutes. In 1834 the average speed of trains on the Liverpool and Manchester Railway was twenty miles an hour; in 1838 it was twenty-five miles an hour. But by 1840 there were engines on the Great Western Railway capable of running fifty miles an hour with a train and eighty miles an hour without. In 1841 we find Stephenson himself ranged on the side of caution, and suggesting that forty miles an hour should be the highest regular speed for trains. Now, it is a remarkable fact that the highest speed at which locomotives run in ordinary practice scarcely seems to have been raised during the last twenty-five years; on the other hand, the weight of the trains has been perhaps doubled. Although the average running time of express trains has in many cases been improved, this has been almost entirely due to their making fewer stoppages. At the same time the speed occasionally attained is very great. Engines on some of our principal lines have repeatedly run fifteen miles in twelve minutes, or at a speed of seventy-five miles an hour, and express trains run regularly at fifty-three miles an hour. It does not follow, however, that there is never

to be any increase in the speed of trains, and it seems a point well worth consideration in what way the time of transit between important centers of trade can be shortened.

What are the causes which have tended to prevent any improvement in this particular? In the first place it may be said that the permanent way would suffer seriously by further increase in speed; but this could surely be overcome in time by improving the permanent way itself, which also remains very much in the same condition and of the same construction as it was twenty-five years ago. Again, it may be said that the running at a higher speed would require more powerful engines, and hence that trains now worked by a single engine would require two, or would have to be spilt up into two trains at a great increase in running expenses. This however assumes that it is not possible so to improve the engine that it shall be able to exert a considerably higher power without an inadmissible increase in weight. By utilizing a larger part of the total weight of the engine as adhesion weight, it would be easy to obtain the amount of adhesion required for the increased tractive force; and for this purpose Mr. Webb's compound locomotive (to be described by the author in a paper he has prepared for this meeting) which enables the number of driving wheels to be increased without the use of coupling rods, appears to merit particular attention.

Another point in which improvement may possibly arise in the future should be noticed. On the Russian railways, where both coal and wood are dear, the burning of petroleum has now taken a practical form. Our member, Mr. Thomas Urquhart, has been very successful in this direction, and is now running locomotives regularly which use only petroleum refuse, and which show a marked economy over coal or wood. To test the point, he prepared three locomotives of exactly the same type, and started them on successive days under exactly similar conditions of weather, train, and section of road. The trips were made both ways, and the results per verst, including fuel required in lighting up, were as follows:

	copecks.
Anthracite, 52.9 Russian pounds... cost	26.35
Wood, 0.0107 cubic sashin, cost....	23.54
Petroleum-refuse, 27.36 Russian pounds, cost.....	11.64

There is thus in this instance an economy of at least 50 per cent. on the side of petroleum, the boiler pressure being from 120 lb. to 130 lb., and the gross load over 400 tons. At the same time the weight of fuel used, as against coal, is diminished by about 50 per cent., which is a most important item.

Although petroleum is scarcely a product of Western Europe, we have to notice on the other hand the progress which has lately been made in the extraction of oil as a waste product from coal, &c. Mr. Jameson has extracted as much as nine gallons per ton from mere shale. It is suggested that markets for such oil will be difficult to find; but it seems allowable to hazard the idea that we may hereafter see our locomotives even in England, running with oil fuel, which would be at once much lighter and much more easily renewed than the coal which is used at present, and get rid of the intolerable nuisance of smoke and dirt. There might in fact be an oil tank and a water tank side by side at every stopping station, and the engine would replenish her store of fuel at the same time as her store of water.

NEW LOCOMOTIVE SIGNALLING APPARATUS.—On June 30, a series of trials was made, upon the branch line of railway from Messrs. Evans & Co.'s Haydock Collieries to Earlstown Junction, of a new automatic locomotive signalling apparatus patented by Messrs. Croft & Lomax. The apparatus consists of a tappet fixed to a sliding bar, which communicates by means of a bell crank with a disc signal upon the engine, in front of the engine driver. In the 4-foot way a metal box is sunk in which an inclined plane is raised or lowered from the signal cabin, as the signals are at "danger" or the reverse. If at "danger" the tappet alluded to in the apparatus strikes upon the inclined plane, and releases a weight communicating with bell crank, which moves a red light, and also an arm danger signal on the engine, and at the same time blows a whistle. Neither of these can be altered until they are attended to by the engine man by means of a lever, so that it would be impossible for him to overlook or neglect the signal, as his attention would of necessity be drawn to it by the continued whistling, which would only cease when put out of action by the driver. The "distant" and "home" signals are exactly repeated on the disc carried by the engine, so that in foggy weather the driver is able to distinguish which signal is indicated by simply looking at the dial on his engine. The tests were made at varying speeds, and in every instance the signal was correctly given. The trials were witnessed by a number of gentlemen interested in the matter, including Mr. John Higson, mining engineer, of Manchester, and the general opinion expressed was one of satisfaction with the results. The apparatus is one that can be readily applied at a small cost, and, judging from the tests made on Saturday, there is little doubt it would contribute towards the safe working of railway traffic, especially in foggy weather, and in working the colliery sidings which crowd upon the main lines in some of the mining and mineral districts.

ACCORDING to experiments made upon the Hanover, Cologne, and Minden Railway, fir sleepers injected with chloride of zinc required a renewal of 21 per cent. in eleven years; birch sleepers injected with creosote required a renewal of 46 per cent. at the end of twenty-two years; oak sleepers injected with chloride of zinc required a renewal of about 21 per cent. at the end of seventeen years: while the same kind of sleepers in their natural state required a renewal of at least 49 per cent. at the end of a like period. The conditions in each of these cases were very favorable for obtaining trustworthy proofs. The subsoil of the line was good; the non-renewed sleepers showed, when cut, that they were. in a sufficiently good state

of preservation. Upon another line where the oak sleepers were not injected, it was necessary to renew them in the proportion of 74 per cent. at the end of twelve years; these same sleepers injected with chloride of zinc required a renewal of only 3.29 per cent. at the end of seven years; whilst those injected with creosote re-required a renewal of only 0.09 per cent. at the end of six years.

On the 1st of June, at 7.30 p.m., the new quick railway service between Paris and Constantinople *via* Vienna and Giurgevo, came into operation. For the present it will be a bi-weekly service both ways, leaving Paris at half-past 7 p.m. on Tuesdays and Fridays; and the train will consist of three saloon carriages, fitted with forty-two beds, a refreshment saloon, and a sufficient number of luggage vans, in which the luggage will be so arranged that it can be examined in the vans by the Customs officers at the frontier stations, thus avoiding the delay and annoyance unavoidable when the luggage has to be removed from the train. There will be no change of carriages between Paris and Giurgevo, and it is expected that the entire journey between Paris and Constantinople will be completed in about seventy-five hours.

The French Government owns 2316 miles of railroad, including a large number of short lines in various parts of the country; but there are 1260 miles in lines which form something like a single system. These are chiefly roads which the companies that undertook them were unable to complete, because they did not seem likely to be profitable. Some of these lines the Government lease to the great companies, some to companies organized especially to work them, and some it works itself. As a whole, they are very unprofitable, the working expenses being 96 per cent. of their gross earnings. On many lines the expenses are more than the gross earnings—30 per cent. more on one line, and 17 per cent. more on others. Including interest, this system has cost £1,600,000 more than it has brought in during three years.

The following description has been given of a wire railway in connection with the coal mining industry established near the Hersteigg, the products of which it brings to the main line belonging to the Southern Railway of Austria. In its alternating rise and fall during its distance of 3,000 yards there is a useful excess of incline of about 142 yards, which, it is said, suffices to keep the line in self-acting working, after it has been started by means of the 12-horse power engine provided for that purpose. When there is no return load to be sent to the mine, the speed of the train can be regulated by a brake. Under these circumstances the cost of working the line is estimated at about 5½ cents per ton of coal. In its general arrangement the railway forms a straight line, and consists of two drawing ropes and the train rope. The line which is used for conveying the coal to the station is 1.10in. thick, and is composed of nineteen steel wires, each 0.18in. in diameter. The line on which the coal vessels are returned to the mine is only 0.66in. thick, the nineteen steel wires of which it is composed being only 0.13in. thick. Both ropes consist of wires about 765 yards long, coupled to each other, and for the ropes a breaking strength of 73 tons per square inch section is guaranteed. At the ends of the ropes weights of five tons and three tons are applied in the usual way for obtaining the proper tension. The distance between the seventeen supports varies from 60 to 400 yards. The train rope is 0.6in. thick, and consists of twelve soft steel wires of 0.07in. in diameter, and runs at a speed of about 1⅝ yards per second. The vessels which convey the coal follow each other at a distance of about 83 yards. Thus thirty-six are always on the way to and the same number coming from the station. Each vessel contains about 10 bushels, or about a quarter of a ton of brown coal, the total quantity carried per hour being about 17½ tons. The cost of the line was about £5,000.—*Engineer.*

In a report to the Board of Trade on the explosion of the boiler of a tank locomotive at Summerlee Ironworks, Coatbridge, in March last, Mr. J. Ramsay says: The locomotive was made for Messrs. the Summerlee Iron Company by Mr. Andrew Barclay, engineer, Kilmarnock, in October, 1869, and was, therefore, upwards of thirteen years old. The inside of the barrel plating is reduced by corrosion to about ¼ in. thick, and over the whole of the surface of the plates that can be seen there is a great deal of pitting; but grooving along the inner edge of a longitudinal seam of the barrel—in the vicinity of the fore left-hand wheel of the locomotive—which has reduced the plate at that part to about $\frac{1}{16}$ in. mean thickness, is undoubtedly the cause of the explosion. Grooved plates are not by any means as strong as thin sound plates of equal thickness, and even if they were as strong they cannot sustain with safety the enormous working stress of 35,000 lb. per square inch of cross-plate section, which was about the stress on the grooved part of the plate when the steam pressure was at 112 lb. per square inch. It is, therefore, not surprising that the explosion occurred. Mr. T. W. Trail adds: It is evident that the boiler was worn out and the inspection inadequate.

ORDNANCE AND NAVAL.

Steel in its Relation to Modern Guns.—At a recent meeting of a number of artillery and naval officers at Karlsborg, Sweden, Captain John Bratt, of the Swedish Artillery, read a paper on "The Steel Industry and its Relation to the Manufacture of Modern Guns." The author has for many years been the Government inspector of Swedish gun factories, and has paid many visits to the gun factories of Russia, Germany, and France. In his paper, having given an account of the importance of iron in modern civilization, the author stated that there was no other raw material which had been subjected to such a successful process of refining. It was in its most important and interesting form—viz. steel—that he intended to deal with it on this occasion. Captain Bratt proceeded to show, by drawings and diagrams,

the metallurgical processes and methods of refining in use at the present moment. Having referred to the various kinds of steel and their manufacture, the author urged the necessity of subjecting all cast steel, of whatever kind, to a mechanical process of treatment by which the cavities which are caused by the gases contained in every steel bath are entirely removed. The steel, he said, should be perfectly close and homogeneous in order to be suitable for manufacture. The means of obtaining this indispensable quality was the steam hammer. The largest at present in use were those at Le Creusot, Essen, and Perm (Russia). The latter rested on the largest block of cast iron in the world. It had a cubic contents of 83 cubic meters, and contained 700 tons of pig-iron. The difficulties, the cost, and, in some instances, the danger of forging great blocks of steel made it a matter of moment to discover some method whereby the gases in the bath might be removed and a homogeneous steel produced. Such a method was discovered in 1870, and had been perfected at Terre-Noire, and consisted chiefly in adding a flux of silicon in the Martin furnace immediately before the steel is tapped. The author showed some samples of steel made at Bofors, in Sweden, by that method. One was taken from the hearth immediately before, and the other just after, the silicon was added. The former had a surface similar to a fracture, and was covered with blisters, whereas that of the latter was perfectly smooth. The Bofors Ironworks were the first Swedish works which had procured the Terre-Noire patent, and thus the first producers of this kind of steel in Sweden; and the method had a special interest to those assembled by the fact that guns of Bofors steel had been manufactured with the most satisfactory result, which led him to believe that Sweden would very soon make her own guns. The author next gave an account of Krupp's manufacture of forged steel guns. The Essen works had in 1848 employed 72 men; in 1882 their number was 16,000, while some years ago they had in five months turned out no less than 1,400 pieces of artillery. In twenty-four hours the works could roll sufficient rails for a Swedish mile of railway (six English miles). Captain Bratt then referred to his personal study of the Krupp method. He had been present at the casting of guns at the foundry which had been established by Messrs. Krupp near St. Petersburg. He stated that the ingots for some of the largest guns numbered up to 500. He then described the heating of the metal for forging, and the difficulties attending this operation, the forging under the steam hammer, whereby the cast metal is compressed to under four times its original size, and, finally, how the gun, after being bored and turned, is made red-hot and hardened in oil. The author next gave an account of the experiments which had during the last few years been made in Sweden, to solve the question of producing first-class guns of close cast steel by the Terre-Noire method. The trials made included the bursting of a smooth-bore 4-lb. muzzle-loading gun. It had sbown a very high degree of resistance, and had, in fact, only been burst by loading it right up to muzzle. No less than 1,041 shots had been fired from a 12-centimeter rifled breech-loader which was at last burst under the excessive pressure in the chamber of 5,500 atmospheres, while the normal one was from 2,000 to 2,100. The last experiment was the firing of three 8-centimeter guns of the new model gun of the Swedish artillery. Each of these guns had, without suffering in the least degree, fired 2,000 shots, with normal charges. Two of them were then, after 152 and 154 attempts had been made, burst, under a pressure in the chamber of 5,000 atmospheres, the normal one being 1,800. The third gun could not be burst, but only cracked in the breech. All these guns had been cast at Bofors, and were finished at the gun factory at Finspong. In conclusion, Captain Bratt stated that lately a competition had sprung up between these two works, which had before worked in concord. This was caused by the fact that the problem, whether first-rate steel guns could be made in Sweden, had been solved, and that these two works desired in future to be independent of each other in gun making. At Bofors there was now erecting the plant required for finishing guns, and at Finspong a steel foundry. Both had received orders from the government, and he trusted that at no distant date they would also receive them from foreign governments.

IRON AND STEEL NOTES.

Basic Steel at Amsterdam. — England, France, Germany, Austria, and Belgium have all alike contributed specimens of basic steel to the Amsterdam Exhibition. The specimens have been got together by Messrs. Thomas & Gilchrist, the inventors of the process, and they testify to a capability by this metal which, viewed in the light of earlier knowledge in this branch of metallurgy, is remarkable. The British specimens from the Patent Shaft and Axle-tree Company's works, at Wednesbury, are designed to show the applicability of the steel to locomotive tubes, tin plates, Galloway tubes and rivets. France contributes striking illustrations of the ductility and the malleability of the metal. The specimens of plate from the Creusot Works have borne the severest punishment, including the flanging 6in. by 6¼in. deep of a central hole and the edges of a plate 59in. thick and 165lb. in weight, and beaten out, the unflanged portion into a stride or A-shape, while the flanged edge is almost elliptical in outline, and the hole circular. The capability of the angle iron appears in the sample bent hot into an S-shape, the upper possessing a smaller radius than the lower curve. The quality of the rails, made also by Messrs. Schneider, is told in the one complete twist on a length of 5ft. 9in., weighing 110lb. The handling of the basic plant by the Hoerde Hutten Verein, Germany, is shown mainly in a large collection of rail sections, tram rails, and sleepers, together with some plates. Similar sections come from the Teplitzer Walzwerk of Teplitz, Austria. The tenacity of the steel comes out in the manner in which the specimens have submitted to cold bending and twisting. Demonstrative of the different degrees of hardness which the metal

can be made to acquire is the circumstance that the carbon in the rails is 0.35 per cent., and that in the rolled sleepers 0.08 per cent. Test pieces made from the sleeper material have a limit of elasticity from 13.4 to 14.6 tons per square inch, a tensile strength of from 25.4 to 27.6 tons per square inch, an elongation of between 29 and 33 per cent., and a contraction of area of between 53 and 63 per cent. Tubes flanged and bent close, cold, yet without sign of fracture, are the contribution from a second Austrian steel works, the Witkowitzer Bergbau. The Belgian contribution is an assortment of wire from the finest to the ordinary thick from the Les Acieries d'Anglear, of Renory, Ougree. The content of carbon in this wire is from 0.12 to 0.15 per cent. The same firm likewise show steel wire upon their own account.—*Engineer.*

RUSSIAN BASIC STEEL.—By Sergius Kern, M.E., St. Petersburg.—It was a very interesting object for the writer to test the qualities of the basic steel of Russian manufacture. Near St. Petersburg, the Alexandrovsky Steel Works are commercially working the basic process in Siemens-Martin furnaces.

The plate steel welds quite like iron; in fact the Nevsky Works, St. Petersburg, rolling the ingots, make, out of the remaining scrap, piles which, heated to a welding heat, are rolled into capital plates for different purposes.

The following are the results of trials of the steel plates:

Unannealed Plate.

Thickness in Inches.	Breaking Weight: Tons per Square Inch.	Elongation in 8 Inches. Per cent.
½	26	29

Annealed Plate.

½	22	36.25

The chemical composition of the steel runs as follows:

	Per cent.
Carbon	0.10
Manganese	0.43
Phosphorus	0.02
Sulphur	0.02
Silicon	traces
Copper	none

I am informed that the raw materials charged into the furnace contain, on the average, 0.75 per cent. of phosphorus.

I am very happy to state that the great invention of Messrs. Thomas & Gilchrist is worked in Russia in such a satisfactory way.

BOOK NOTICES

PUBLICATIONS RECEIVED.

MONTHLY WEATHER REVIEW FOR APRIL AND MAY. Washington: Office of Chief Signal Officer.

PAPERS OF THE INSTITUTION OF CIVIL ENGINEERS.—Through the kindness of Mr. James Forrest we are in receipt of the following:

Covered Service Reservoirs. By William Morris, M. I. C. E.

The Behavior of Steam in the Cylinders of Locomotives during expansion. By Daniel Kinnear Clark, M. I. C. E.

Slipway for Pleasure Boats. By Charles James More, M. I. C. E.

Tests of Riveted Joints. By Charles Henry Moberly, M. I. C. E.

Weights of Structures Estimated Graphically. By Joseph Heywood Watson Buck, M. I. C. E.

Wire-Rope Street Railroads. By William Morris, M. I. C. E.

Long-Distance Telephony. By George M. Hopkins.

The Electrical Transmission and Storage of Power. By Dr. C. William Siemens, F. R. S.

Summit-Level Tunnel of the Blaenau-Testiniog Railway. By William Smith, M. I. C. E.

Machine Tools. By Alexander McDonnel, M. I. C. E.

Irrigation in Colorado. By Patrick O'Meara.

SIGNAL SERVICE NOTES.—No. 4.—The Use of the Spectroscope in Meteorological Observations. By Winslow Upton, A. M.

No. 5.—Work of the Signal Service in Arctic Regions. Under direction of Maj.-Gen. W. B Hazen. Washington: Office of Chief Signal Officer.

STEAM HEATING. An Exposition of the American Practice of Warming Buildings by Steam. By Robert Briggs, M. I. C. E. Science Series No. 68. Price 50 cents. New York: D. Van Nostrand.

At no time has the demand for a knowledge of the details of the steam heating system been more urgent than now. No other plan accomplishes the heating of whole neighborhoods from a single source; and as this promises to be the method of the future, the inquiry for specific information has been lately very brisk.

This little treatise of the late Mr. Briggs is not new. It has been previously published on both sides of the Atlantic, but the previously available has been exhausted, and the want for such information as this essay affords is more plainly manifest than ever before.

It is put in a compact form as becomes a practical essay, and the mechanical details are illustrated.

PRACTTICAL ELECTRIC LIGHTING. By A. Bromley Holmes. London and New York: E. & F. N. Spon. Price $1.50.

This is an outline of the Science of Electric Lighting, beginning with the simplest facts and phenomena and extending to later applications, including the use of secondary batteries.

Of course, in only 154 pages nothing is fully treated; but enough is given for the purposes of the reader who requires only a brief statement of the whole subject. The number of such persons at present is certainly large.

WATER SUPPLY. By Wm. Ripley Nichols. New York: John Wiley & Son. Price $2.50.

This important subject is here treated from a chemical and sanitary standpoint. The power of water to dissolve various substances is first considered in an introductory chapter. Then in order are presented: Chapter I.—Drinking-Water and Disease. Chapter II.—Water Ana-

lysis. Chapter III.—Rain Water as a Source of Supply. Chapters IV. and V.—Surface Waters as Sources of Supply. Chapter VI.—Ground Water as a Source of Supply. Chapter VII.—Deep Seated Water as a Source of Supply. Chapters VIII. and IX.—Artificial Improvement of Natural Water. Chapter X.—General Considerations.

The treatise forms a most valuable supplement to the works which treat water supply from the engineering point of view only, and is quite as important to the engineer.

ELEMENTARY APPLIED MECHANICS. Part II. By Thomas Alexander, C. E., and Arthur Watson Thomson, C. E., F. R. S. London: Macmillan & Co.

In this second volume of their Applied Mechanics the authors have treated the subject of transverse stress and strain in a systematic manner. Bending movements and shearing forces are considered for the different conditions of loading usually met with, the loads being fixed or moving, or both combined.

In treating of bending and shearing, the common forms of cross-section are given, together with some not much employed. The calculus is employed in a few cases, but students not familiar with it will be able to apply the results.

POCKET MANUAL FOR ENGINEERS. By John W. Hill. Providence: William A. Harris. Price $1.50.

The author of this manual has become widely known as an expert in matters relating to mechanical engineering. His reports upon trials of engines and boilers are referred to as familiar facts by engineering writers on both sides of the Atlantic.

Mr. Hill only claims for the book that it "contains a limited number of facts, data and formulæ, together with several practical illustrations in steam and mechanical engineering, which, it is hoped, will be of value to the profession and others."

It is fair to presume that the collection of formulæ and tables is just what is needed by the working mechanical engineer.

THE SEVENTH VOLUME OF THE SANITARY ENGINEER. New York: The Sanitary Engineer. Price $3.00.

Among the articles of permanent value may be mentioned "Letters to a Young Architect on Heating and Ventilation." By Dr. J. S. Billings, U. S. A.

"Steam Fitting and Steam Heating." By "Thermus." A series. (Illustrated.)

"The Edison System of Wiring Buildings for the Electric Light." (Illustrated.)

Illustrated descriptions of the sanitary arrangements in the residences of Cornelius Vanderbilt, Esq., the Berkshire Apartment House, Home for Aged Females, and the Duncan Office Building.

"The Steam Heating Companies in New York." Illustrated description of.

Full abstract, with illustrations, of the records in the "M'Closkey Patent suit for Trap Ventilation."

"The New York Water Supply;" a series of articles on the suppression of waste of water, giving the experience of European cities in attempting to deal with this problem, the practice now in vogue there, and the situation in American cities. These articles will be found of great value to water works authorities and all who are interested in this question.

A discussion of the various projects for increasing the water supply of New York, including the Croton Aqueduct scheme, appears in almost every number in this volume.

"Atlantic Coast Resorts." A report by E. W. Bowditch, C. E., to the National Board of Health.

"How the Plumbing Law is enforced in New York." A description of the methods employed by the department.

"Germs and Epidemics." By Dr. John S. Billings, U. S. A.

"Malaria" (a series). By George M. Sternberg, Surgeon U. S. Army.

"Gas Fitting in an Office Building;" description of work in Mills Building.

"American Practice in Warming Buildings by Steam." By the late Robert Briggs, M. Inst. C. E.

The value of these articles is undoubted, and the plan of putting the collection in a permanent form is an excellent one.

The reader of the volume may feel assured that he finds there presented the thoroughly scientific methods of sanitary reform.

MAN BEFORE METALS. By N. Joly. New York: D. Appleton & Co. Price $1.75.

This is a late addition to the International Scientific Series. The subjects treated are: Prehistoric Ages—The work of Boucher de Perths; The Bone Caves; The Peat Mosses and Kitchen Middens; The Lake Dwellings and the Meraghi; Burial Places; Prehistoric Man in America; Man of the Tertiary Epoch; The Great Antiquity of Man.

Part II. is devoted to Domestic Life, Industry, Agriculture; Navigation, and Commerce, The Fine Arts, Language and Writing, Religion, The Portrait of the Quaternary Man.

The work is a compact and skillful treatise, presenting an epitome of the latest discoveries and best writings on the subject of the earlier stages of development of the human race.

MINERAL PRODUCTS OF THE UNITED STATES. —A report entitled "The Mineral Resources of the United States" is now in press, and will shortly be published, by Mr. Albert Williams, jr., chief of the Division of Mining Statistics and Technology, United States Geological Survey, Hon. J. W. Powell, Director. This report is for the calendar year 1882 and the first six months of 1883. It contains detailed statistics for these periods and also for preceding years, together with much technical and descriptive matter. The compilation of special statistics has been placed by Mr. Williams in the charge of leading authorities in the several branches, and the results will therefore be accepted with confidence. An abstract given in the prospectus, presents a summary of the productions of the following

Coal, iron, gold, silver, copper, zinc, lead, tin, nickel, cobalt, mercury, manganese, petroleum, salt, marl, mica, soapstone, brick and tile, lime, cement, graphite, and precious stones.

A Manual of Marine Engineering, comprising the Designing, Construction, and Working of Marine Machinery. By A. E. Seaton, Lecturer on Marine Engineering to the Royal Naval College, Greenwich, M.I.N.A., M.I.M.E., &c. London: Charles Griffin & Co., 1883.

The wonderful activity which has prevailed during the last few years in the shipbuilding industry, and the rapid development of the marine engine, has created an opening for a thoroughly good and comprehensive work dealing with the application of theoretical principles to the design and construction of marine machinery, especially in its later forms, and this opening has found a worthy response in the volume before us, in which may be discerned the results of much close study and practical work among marine engines. Although the work is thoroughly up to date, and deals with such recent examples as the Arizona and the City of Rome, yet it traverses the whole area of its subject, beginning with a general explanation of the object aimed at by the marine engineer, viz., the propulsion of a ship through the water, and the means by which this is effected. It then turns to the subject of power and the methods by which it is measured and expressed in the case of the steam engine, considering the various sources of loss and the means by which they may be minimized or overcome by the aid of skillful design. The next point is naturally the resistance of ships and the indicated horse power necessary for speed, and this, although not strictly within the province of the designer of engines, is treated at considerable length, and all the best approved methods of calculation are given. The power of the engines having been thus determined, the author discusses the space occupied by them, pointing out the peculiarities of each type in this respect, and the kind of work for which it is best suited. Two chapters are then devoted to the consideration of the action of the steam in the cylinders, and the comparative advantages and disadvantages of high and low grades of expansion, compounding and non-compounding, the use of two, three, four, and six cylinders, the ratio of cylinder capacity, and the like. Leaving this somewhat theoretical subject we find several successive chapters appertaining to mechanical details, each principal part of the engine being treated separately, ample information being given concerning the strains to which it will be subject, together with many reliable formulæ for the determination of its dimensions, aud tables of examples compiled for actual practice.

As might be anticipated, the question of valves and valve gears receives considerable attention. The author begins with a short historical account of the various kinds that are employed, and then explains the method of designing different kinds of valves. From this he proceeds to the link motion and describes the different modified arrangements that have been offered in place of it, such as Hackworth's, Marshall's, Joy's, and Sell's gear. We then come to the portion devoted to boilers, which occupies four chapters. The first relates to combustion and evaporation, the second to the general design, the third to construction and detail, and the fourth to mountings and fittings. After the boilers there follows a considerable amount of miscellaneous information relating to fitting the engines to the ship, to steam pipes, reversing gear, turniug gear, governors, gauges, feed heaters, and materials.

Thus our readers will see that this important subject of marine engineering has been treated with the thoroughness that it requires, and that no department has escaped attention, while the observations on each bear evidence of being the outcome of a quick, practical mind, trained in the workshop and drawing office, and not in the lecture room. The volume is well printed and liberally illustrated, some of the engravings, however, being scarcely so good as the book deserves. The frontispiece, showing the engines of the s.s. Arizona, is by the way, copied from our own columns, a fact which the author has omitted to mention.—*Engineering.*

MISCELLANEOUS.

Adhesive Power of Nails and Screws.—The extensive use to which nails and screws are put in construction lends considerable interest to any records of experience tending to discover their holding power. Haupt, in his "Military Bridges" gives a table of the holding power of wrought-iron 10d. nails, 77 to the pound, and about 3 inches long. The nails were driven through a 1-in. board into a block, and the board was then dragged in a direction perpendicular to the length of the nails. Taking a pine plank nailed to a pine block with eight nails to the square foot, the average breaking weight per nail was found to be 380 pounds. Similar experiments with oak showed the breaking weight to be 415 pounds. With 12 nails to the foot square the holding power was 542½ pounds, and with six nails in pine 463½ pounds. The highest result obtained was for 12 nails to the square foot in pine, the breaking weight being in this case 612 pounds per nail. The average strength decreases with the increase of surface. Tredgold gives the force in pounds required to extract 3d. brads from dry Christiana deal at right angles to the grain of the wood as 58 pounds. The force required to draw a wrought iron 6d. nail was 187 pounds, the length forced into the wood being 1 inch. The relative adhesion when driven transversely and longitudinally is, in deal, about 2 to 1. To extract a common 6d. nail from a depth of 1 in. in dry bench, across grain, required 167 pounds; in dry Christiana deal, across grain 187 pounds, and with grain, 87 pounds. In elm the force required was 327 pounds across grain, and 257 with grain. In oak the figure given was 507 pounds across grain. From further experiments it would appear that the holding power of spike nails in fir is from 460 to 730 pounds per inch in length, while the adhesive power of screws 2

in. long, 0.22 in. in diameter at the exterior of the threads, 12 to the inch, driven into ½ in. board, was 790 pounds in hard wood, and about one half that amount in soft wood.

SUBSTITUTE FOR GUTTAPERCHA.—A German chemist, Herr Maximilian Zingler, has just patented a new process for manufacturing a substitute for guttapercha. About 50 kilogrammes of powdered copal, and 7½ to 15 kilogrammes of sublimed sulphur are mixed with about double the quantity of oil of turpentine, or with 55 to 66 liters of petroleum, and heated in a boiler provided with a stirring apparatus to a temperature of 122 degrees to 150 degrees C., and stirred until completely dissolved. The mass is then allowed to cool to 38 degrees C., and is then mixed with about three kilos of casein in weak ammonia water, to which a little alcohol and wood spirit has been added. The mass is then heated to the former temperature (122 degrees to 150 degrees C.) until it is a thin fluid. It is then boiled with a 15 to 25 per cent. solution of nutgall or catechu, to which about half a kilo of ammonia has been added. After boiling for several hours the mass is cooled off, washed in cold water, kneaded in hot water, then rolled out and dried. It is claimed that the product is produced much cheaper, and cannot be detected from the real article. It is said to wear equally as well.

AN ASPHALTE MORTAR.—The *Centralblatt der Bauverwaltung* describes a patented composition made at a factory in Stargard, Pomerania, which has for some years past been used with perfect success on the Berlin-Stettin railway for wall copings, water-tables, and similar purposes requiring a waterproof coating. The material is composed of coal tar, to which are added clay, asphalte, resin, litharge and sand. It is, in short, a kind of artificial asphalte, with the distinction that it is applied cold, like ordinary cement rendering. The tenacity of the material when properly laid, and its freedom from liability to damage by the weather, are proved by reference to an example in the coping of a retaining wall which has been exposed for four years to the drainage of a slope 33ft. high. This coping is still perfectly sound, and has not required any repair since it was laid down. Other works have proved equally satisfactory. In applying this mortar, as it is termed, the space to be covered is first thoroughly dried, and after being well cleaned is primed with hot roofing varnish, the basis of which is also tar. The mortar is then laid on cold to thickness of about three-eighths of an inch, with either wood or steel trowels, and is properly smoothed over. If the area covered is large, another coating of varnish is applied, and rough sand strewn over the whole. The waterproof surface thus made is perfectly impregnable to rain or frost, and practically indestructible. The cost of the material laid is estimated at not more than 5*d.* per square foot; and it is stated that this price can be reduced by at least 1*d.* for large quantities put down by experienced workmen.

AN exchange says: The Reading Railroad Company has been testing an ingenious device for lighting the platforms and steps of railroad cars at night, and also station platforms in the vicinity of the car steps. The object of the device is obtained by means of a lantern placed under the steps of the car. The rise of each step is provided with a window of thick plate glass, through which the light illuminates the steps. In the back of the lantern is set a door which has a bull's-eye of suitably colored glass, through which the light also shines, and may serve as a substitute for the danger and other signals usually placed upon the platform or railing of the rear car. The lamp inside the lantern is an ordinary double-wick burner, and for the purposes of illumination on the trial trips mineral sperm oil was used. The lamp appears to have withstood the shocks of coupling and the jars incident to the application of air brakes to the train, going through tunnels and passing moving trains without a noticeable flickering of the flame from excessive drafts, or a dislocation of any part of the lamp from shocks. It not only lit up the steps and a space of 5 ft. to 6 ft. on either side, but also the ground beneath and around them, thereby enabling passengers to see both the steps and the platform when the train was drawn up at a statian. Apart from guarding against accidents and consequent risk of life, other advantages are claimed.

SCALE OF HARDNESS OF COMMON VESSELS.—A new scale for comparing the hardness of metal has been compiled by Mr. Galliner, who in his experiments used small cylinders with conical points, and passed them loaded up to five kilogrammes over polished plates of the respective metals, from which they did not materially differ in hardness. Thus he found, indicating the hardness of pure soft lead by 1, that tin is represented by 2; hard lead by 3; copper 4 to 5; metal for bearings (85 copper, 10 tin, and 5 zinc) 6; tempered cast iron 7; fibrous wrought iron 8; grey cast iron 10 to 11; mild steel 12 to 13; crucible steel, blue 14, violet 15, straw color 16; hard bearing metal (83 copper, 17 zinc) 17; and very hard steel 18.

THE OHM AND "MHO."—During his recent lecture at the Institution of Civil Engineers, Sir William Thomson proposed the term *mho* for a unit of conductivity. Conductivity is the reciprocal of the resistance which is measured in ohms, and *mho* is found by saying "ohm" into a phonograph, and then turning the drum backward. How Sir William finds the reciprocal of a value equivalent to a word spoken backwards he does not explain, and, on the whole, we think he has chosen a somewhat fanciful way of finding a new electric term. Nevertheless, a convenient unit word for conductivity would be useful. We may add that in Sir Willam's opinion electricians may safely take the British Association unit of resistance as 0.9868 of the true ohm defined as 10^9 centimeters per second, or the Siemens unit as 0.9413 of the ohm.